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SRI PUFF 8 COMPUTER PROGRAM FOR
ONE-DIMENSIONAL STRESS WAVE PROPAGATION

Prepared by

SRI International
333 Ravenswood Avenue
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March 1980



US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
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<p>SRI PUFF 8 is a Lagrangian finite difference computer program for calculating one-dimensional stress wave propagation through solid, liquid, gaseous, and porous materials. The stress waves may be caused by the deposition of radiant energy, impact of materials, explosive detonation, or by a prescribed pressure or velocity history.</p> <p>The calculational procedure is the standard leapfrog method of von Neumann and Richtmyer using artificial viscosity to smooth shock fronts. Rezoning and</p> <p style="text-align: right;">(cont'd)</p>		

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material separation by spall are permitted. Planar, cylindrical, and spherical flow are treated.

The constitutive relations include the standard Mie-Grüneisen equation of state and elastic, plastic (Mises or Coulomb) work-hardening deviator stress relations with thermal softening. Other pressure relations provided are a polytropic gas for explosives, GRAY and Philco-Ford three-phase equations of state, and a tabular pressure-volume relation. Special deviator stress models include the standard linear viscoelastic model, a Bauschinger model, dislocation models, and a nonlinear work-hardening model. Ductile and brittle fracture and shear banding are provided by nucleation and growth models. Porous materials may be represented by the Seaman-Linde model, Holt model, Herrmann $P-\alpha$ model, a cap plasticity model, a variable modulus model, Butcher $P-\alpha-\tau$ model, or by a linear viscous void compaction model. A model for layered composites is also present.

The code is constructed for easy insertion of additional material models. The number of extra variables required for each cell for a material model can be specified in the input deck.

This manual includes many sample problems, a derivation of the flow equations, discussion of material models, and an outline of other aspects of wave propagation calculations.

FOREWORD

This volume constitutes a portion of the three-volume final report to Ballistics Research Laboratory on Contract DAAK11-77-C-0083, SRI Project 6802. Volume I reports on ballistic experiments and calculations, and describes work on the latest version of the SRI brittle fracture subroutine. Volume III is the manual for the two-dimensional wave propagation code TROTT.

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1. INTRODUCTION

The SRI PUFF code is a computer program for calculating one-dimensional stress wave propagation through solid, porous, liquid, or gaseous materials. The stress waves being computed are initialized by the deposition of radiated energy from x-ray, electron beam, or laser sources; impact of one material on another; detonation of an explosive; or by prescription of a pressure or velocity history at a boundary. Computations are made with the Lagrangian form of the equations of motion so that the coordinates move with the materials. An artificial viscosity is used to smear wave fronts over several computational cells.

1.1 Background

In 1950 von Neumann and Richtmyer (Ref. 1) initiated the artificial viscosity (or Q) method for solving the equations of wave propagation. With this technique infinitely steep shock fronts cannot develop, and the entire field can be treated as one of continuous flow. Shock fronts appear as regions of high stress gradient, not as discontinuities. The viscosity tends to dampen all oscillations or perturbations in the flow field. Several integration schemes based on the Q method have been developed, notably the Lax-Wendroff method (Ref. 2), the Runge-Kutta-Gill method (Ref. 3), and the "leapfrog" scheme (Ref. 1) which is used by most PUFF codes.

The present line of PUFF codes seems to have originated around 1958 with the development of the SHARK (Ref. 4) and SHARP (Ref. 5) codes. With later developments at the Air Force Special Weapons Center, Kirtland Air Force Base, the generic name PUFF was given to the program. Recent versions include PUFF (Refs. 6-8), PUFF III (Ref. 9), PUFF IV (Ref. 10), PUFF IV-EP (EP for elastic-plastic), (Ref. 11), PUFF V-EP (Ref. 12), PUFF VTS (variable time step), (Ref. 13) FOAM PUFF (Ref. 14), PUFF 66 and P PUFF 66 (Ref. 15).

Most of the PUFF codes have been described in classified reports, so their characteristics cannot be outlined here. A useful review of the capabilities of each of these codes has been provided by Bothell and Archuleta (Ref. 11). Other PUFF-type codes are available under the names of WONDY (Ref. 16), SRI PUFF (Ref. 17), and RIP (Ref. 18). RIP is a well-documented code with special capabilities including detailed treatment of composite materials and laser deposition. All the PUFF-type codes use artificial viscosity with the leapfrog integration scheme. The SRI PUFF series of codes began as a modification of the PUFF 66 and P PUFF 66 codes.

1.2 Scope

This volume outlines the essential theory on which the wave propagation calculations of the SRI PUFF series of computer programs is based and describes some of the constitutive models (stress-strain relations) currently available. The constitutive models include several that provide deviator stress only, several for pressure only, and several that provide a combination of pressure and deviator stress. The descriptions given here outline the simplest constitutive models only, indicate sources for information on the others, and show how to insert additional constitutive models.

The current version of SRI PUFF includes the features of earlier versions plus provisions for cylindrical and spherical flow as well as one-dimensional planar flow; use of a data bank; ductile and brittle fracture, fragmentation, and shear banding; several porous material models; a hypoelastic (variable modulus); a cap (advanced plasticity) model; detonation by constant volume explosion or by running detonation; improved rezoning; and Coulomb-friction without dilatation.

The code calculations make use of both linear and quadratic artificial viscosity. An integral approach is used to solve the mass and energy conservation relations. The stress is determined from the equation of state or constitutive relations for known volume and energy. Because the energy is not known at the time stress must be calculated, an energy estimate is made and then adjusted after the stress calculation.

Since its outgrowth from PUFF 66 in 1967, SRI PUFF has undergone many changes and is expected to undergo more. The code is written in a modular form so that initialization and running are usually separated, deposition problems use subroutines that are unused for other runs, and constitutive relations are in separable subroutines. Thus the code is planned for ease of change. Subroutines for new constitutive relations can be added as new material models are generated.

This manual is intended to assist not only the users of the program, but also those who wish to understand it well enough to modify it, and those who wish to investigate the analytical basis of the program. For users, the chapter on Initialization (Section 5), and the Appendices C (Input) and J (Glossary) will be of primary interest. Alterers of the program may notice the following features: a brief description of each subroutine in Section 2 and a discussion of major subroutines is at the end of Sections 2 through 6. For the analyst, the bases of the program are discussed in Sections 3 through 5, which is organized around certain fundamental problems in the program: initializing, integration of the propagation equations, equations of state, and so forth. The order of presentation is general theory first, then application to the current analysis, and finally details of implementation in the program. It is hoped that this organization will provide answers to specific questions about the program.

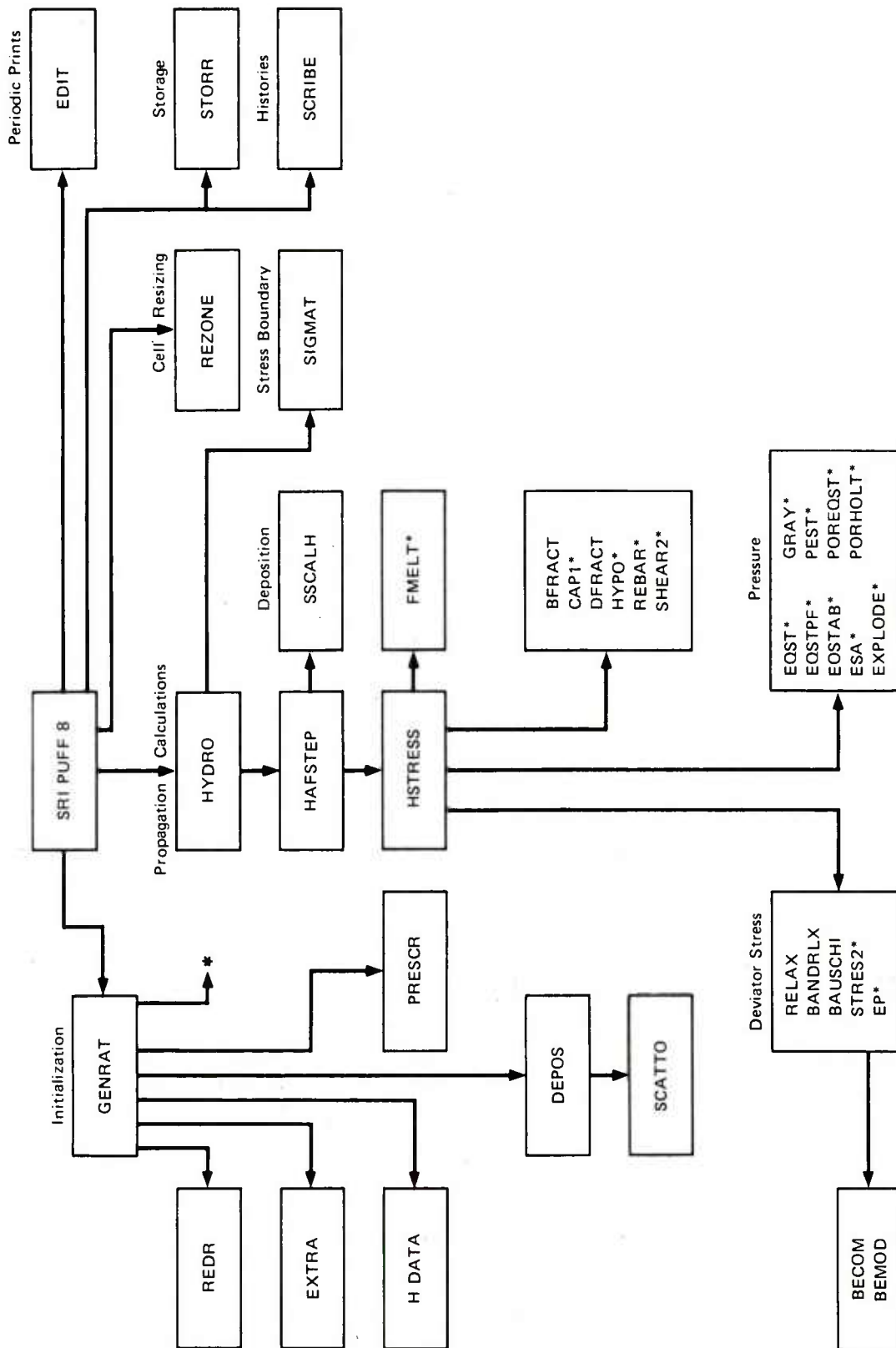
2. ORGANIZATION OF THE CODE

2.1 Summary

SRI PUFF 8 is a one-dimensional Lagrangian hydrodynamic program for the computation of stress waves caused by impact, radiation deposition, detonation of an explosive, or prescription of a stress or particle velocity at a boundary. The numerical integration of the governing equations is carried out with the leapfrog method of von Neumann and Richtmyer. The computations proceed by increments of time. For each increment, a cycle of computations is made throughout the active regions of the materials to determine stress, particle velocity, specific internal energy, density, sound speed, yield strength, pressure, coordinate location, and other variables. The primary routines of the program are SRI PUFF 8 (overall control), GENRAT (initialization), HYDRO (control of wave propagation calculations for each cell), HAFSTEP (density and energy calculations), and HSTRESS (control of stress calculations).

The flow of program control is illustrated schematically in Figure 2.1, which shows the interrelationship between the subroutines and the main program. The subroutines are grouped according to type of activity. Thus the GENRAT group (GENRAT plus all subroutines with arrows from GENRAT) initializes and the HYDRO group (HYDRO, HAFSTEP, and HSTRESS) treats propagation and stress calculation. The arrows designate direction of calling. A brief description of the work of each subroutine follows:

- SRI PUFF 8, the main program, sets the size of each time increment, calls HYDRO to perform a cycle of computations, and calls for printout and resizing of cells.
- BANDRLX computes deviator stresses according to the Band or Gilman stress-relaxation models (see Ref. 19).
- BAUSCHI computes deviator stresses from a Bauschinger model (see Refs. 19, 20).
- BECOM and BEMOD, in combination with STRESS, compute deviator stress for beryllium according to a stress-relaxing, Bauschinger model (see Ref. 21).



*Starred stress-strain routines are also called by GENRAT for initialization.

FIGURE 2.1 FLOW CHART OF SRI PUFF 8

- BFRACT computes stress and crack sizes in material undergoing brittle fracture and fragmentation (see Refs. 22-25).
- CAP1 computes stress and tensile fracture in materials with a combined Mohr-Coulomb yield and compaction behavior (see Ref. 33).
- DEPOS controls deposition of radiant energy into the cell layout during initialization (see Section 5.4, Appendix A).
- DFRACT computes stress and void growth in material undergoing ductile fracture (see Refs. 23, 26).
- EDIT prints a listing of velocities, stresses, and other variables at specified times (see Section 6).
- EOSTAB computes pressure from a table of pressures as a function of density and energy.
- EPLAS computes elastic plastic behavior of the reinforcing steel treated in the REBAR subroutine (see Ref. 33).
- EQST provides the Mie-Gruneisen and PUFF expansion equations of state for determining pressure (see Section 4).
- EQSTPF contains the Philco-Ford equation of state, which treats explicitly solid, liquid, and gaseous as well as mixed phases (see Refs. 27, 28).
- ESA is an equation of state written in a form that is easy to fit to experimental data (see Ref. 28).
- EXPLODE provides the equation of state for explosives and for constant volume or running detonation (see Appendix B).
- EXTRA reads in additional input outside the normal set (see Appendix C).
- FMELT computes the variation of strength with temperature (see Appendix D).
- GENRAT reads or controls input, and initializes arrays and indicators (see Section 5).
- GRAY provides the Gray equation of state, which treats explicitly solid, liquid, gaseous, and mixed phases (see Refs. 28, 29).
- HAFSTEP computes density and estimates internal energy, then calls HSTRESS for the stress calculation (see Section 3).
- HDATA reads extra input lines for initializing the H(J,I) indicator array.
- HSTRESS computes the stresses through calls to appropriate subroutines. All constitutive relations are reached through the calls by HSTRESS (see Sections 3, 4).
- HYDRO conducts each cycle of calculations through the coordinate array, computes coordinate location and velocity, and calls HAFSTEP for midcell calculations (see Section 3).

- HYPO computes pressure and deviator stress from a variable modulus or hypoelastic stress-strain relation (see Ref. 30).
- PEST provides a stress-strain relation for porous materials, including strain-rate effects, hysteresis, thermal strength reduction, and fracture (see Ref. 28).
- POREQST computes pressure in a porous material, allowing for hysteresis and thermal strength reduction (see Ref. 31).
- PORHOLT computes pressure in a porous material according to the Holt curve for compaction (see Refs. 32, 28).
- PRESCR initializes the indicators required to obtain historical listings (see Appendix C).
- REBAR computes stresses in a layered composite such as reinforced concrete (see Ref. 33).
- REDR positions the tape for reading when input is from a tape file (see Appendix C).
- RELAX computes relaxation of the deviator stress for the anelastic model and a two-parameter, varying yield model (see Ref. 19).
- REZONE resizes the cells and recomputes all coordinate quantities (see Appendix E).
- SCATTO distributes the radiated energy of a depth-dose profile into the cells of the PUFF layout (see Appendix A).
- SCRIBE stores historical data during the computation and provides stress histories at selected coordinates and at each material interface at the end of each computation (see Section 6).
- SHEAR2 contains stress-strain relations for material undergoing yielding and fragmentation by shear banding (see Refs. 34, 35).
- SIGMAT provides a pressure history for a boundary condition.
- SSCALH computes the energy deposited at midcell points during each time increment in which radiation is occurring (see Appendix A).
- STORR stores variables during the calculation for the historical listing (see Appendix C).
- STRES2 computes the deviator stress for beryllium from a stress-relaxing, Bauschinger model (see Refs. 21, 36).
- TSQE provides a computation of density from the Mie-Gruneisen equation of state, given the pressure and energy (see Ref. 28).

2.2 Main Program: SRI PUFF 8

The main program controls sequencing of the operations of initialization, calculation, printout, rezoning, and stopping of the program. It also governs the time increment. The order of operations in the main program is as follows:

- (1) Call GENRAT to read data and initialize COMMON storage.
- (2) Call HYDRO to make computations of all array variables at each time increment.
- (3) Call STORR to store data from HYDRO cycle for later printout.
- (4) Check whether the program should be terminated because:
(a) the problem time (TIME) has exceeded the specified stop time TS; (b) the number of cycles N has exceeded the specified total number of cycles JCYCS; (c) the coordinate of the zone of maximum stress has exceeded the specified coordinate CKS; (d) LSUB(7) has been set to 1 because of an error detected in the computations. If termination is indicated, SCRIBE is called to print a history of stresses. Then the program returns to step 1 to read in the next data deck. If termination is not called for, the program continues to step 5.
- (5) Calculate next time increment DTNH.
- (6) Call EDIT for printout if TIME equals one of the TEDITS (input quantities).
- (7) Call REZONE if the TIME equals a TEDIT time designated for rezoning or if N is a cycle designated for periodic rezoning.
- (8) Prepare for the next EDIT listing. (After completion of this sequence, the program returns to step 2 for the next call to HYDRO.)

The time increment is based on the minimum of the natural time steps allowed (for stability of the calculations) at any point in the mesh. This calculation of permitted time step is described in Section 3.4 on Propagation. The time increment is initialized in GENRAT at 10^{-12} second for the first cycle. Thereafter, the time step increases gradually in successive cycles, to 80% of the natural time step. The increment is never required to be less than 2.8% of the natural time step: then, if a short increment occurs, the increment returns to its normal value within 20 cycles.

To ensure that an adequate number of cycles occurs during the radiation deposition, the time increment during deposition is required not to exceed 0.03 times the duration of any currently active radiation sources. After deposition is complete ($TIME > SSTOPM$), SDURM is reset to 1.0 to indicate that the radiation time step control should be skipped.

3. PROPAGATION CALCULATIONS: HYDRO GROUP

The motion and stresses throughout the material are determined as a function of time in the code. The solution is obtained by solving the mass, momentum, and energy conservation relations together with constitutive relations for the material. This section presents the conservation relations and their general solutions and shows specific solutions for interior points and boundaries of material layers.

In the solution procedure, the material is first divided into discrete units or cells. Motions, energies, and other quantities are initialized in cells as required for the particular problem. Then a time step is taken and the motions and stresses are calculated for each cell using the conservation and constitutive relations. This process of stepping forward in time and performing calculations for each cell is repeated until the time has reached the duration of interest. The time step used is controlled by stability and smoothness criteria in the code. The stability considerations are described in this section. At the end of the section, the major work of the HYDRO group (HYDRO, HAFSTEP, HSTRESS) is summarized.

3.1 Solution Procedure for Wave Propagation Equations

The PUFF programs are all based on the solution of the Lagrangian equations governing one-dimensional motion of a continuous medium. The solution technique is called the method of artificial viscosity because of the introduction of viscous forces to permit a continuous-flow computation in regions of high-stress gradients. Such regions are interpreted as locations of shock fronts, although no discontinuities occur in the computed flow field. With this artificial viscosity method, the equations of continuous flow can be used everywhere and no special equations are required for shock fronts. SRI PUFF uses the leapfrog method of von Neumann and Richtmyer to integrate the flow equations.

The following paragraphs introduce the governing differential equations for planar flow. These are changed to an integral form for solution in the program. The corresponding equations for one-dimensional cylindrical and spherical flow are given in Appendix F.

The one-dimensional planar Lagrangian differential equations to be solved are

$$\left(\frac{\partial U}{\partial t}\right)_H = - \frac{1}{D_o} \left(\frac{\partial R}{\partial H}\right)_t \quad (\text{momentum}) \quad (3.1)$$

$$\left(\frac{\partial X}{\partial t}\right)_H = U \quad (\text{velocity}) \quad (3.2)$$

$$\left\{ \begin{array}{l} \left(\frac{\partial D}{\partial t}\right)_H = - \frac{D^2}{D_o} \left(\frac{\partial U}{\partial X}\right)_t \text{ or equivalently} \\ \left(\frac{\partial X}{\partial H}\right)_t = D_o / D \end{array} \right. \quad (\text{mass}) \quad (3.3)$$

$$\left\{ \begin{array}{l} \left(\frac{\partial E}{\partial t}\right) = - \frac{R}{D_o} \left(\frac{\partial U}{\partial H}\right)_t + \left(\frac{\partial E_{\text{rad}}}{\partial t}\right)_H \text{ or, equivalently} \\ \left(\frac{\partial E}{\partial t}\right)_H = - R \left(\frac{\partial V}{\partial t}\right)_H + \left(\frac{\partial E_{\text{rad}}}{\partial t}\right)_H \end{array} \right. \quad (\text{energy}) \quad (3.4)$$

where H = Lagrangian coordinate location (original position in laboratory coordinates)

X = Eulerian coordinate location (current position in laboratory coordinates)

t = time

U = particle velocity

D, D_o = current and original density

R = total mechanical stress

E = internal energy

E_{rad} = radiated energy

$V = D^{-1}$ = specific volume

These equations relate velocity to the coordinate motion and provide for conservation of momentum, mass, and energy. In addition to these differential equations, there is an equation of state (or constitutive relation (which is a relationship between stress or pressure quantities and the density, internal energy, history of loading, and so forth.

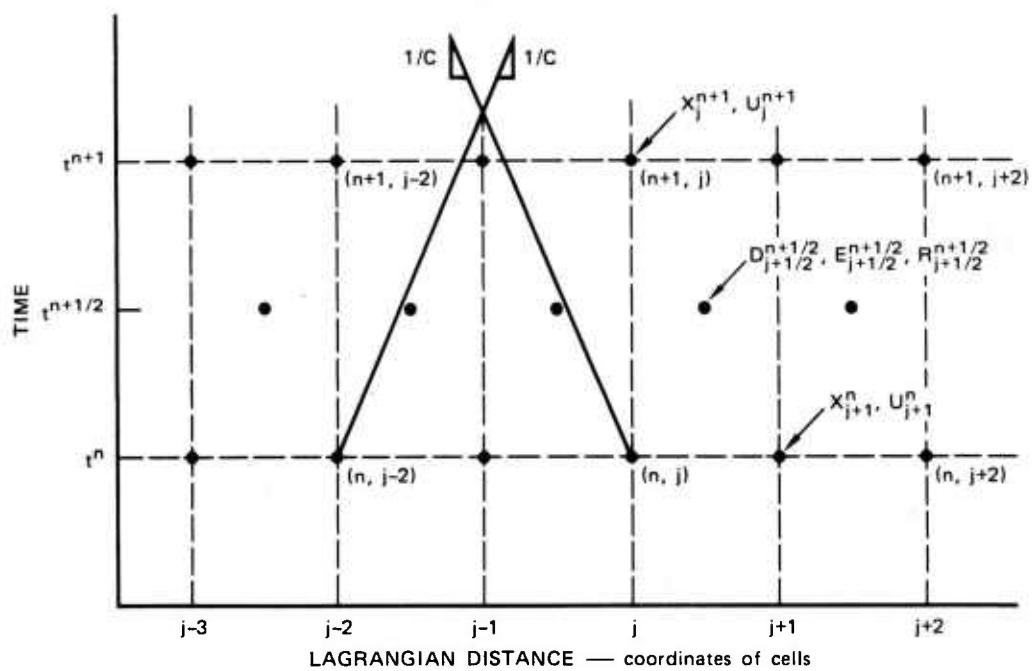
$$R = F(E, D, \dots) \quad (\text{equation of state}) \quad (3.5)$$

$$= P + \sigma' + Q \quad (3.6)$$

The total mechanical stress (in the direction of propagation), R , is composed of the pressure P , the deviator stress σ' in the direction of propagation, and an artificial viscous stress, Q .

In the code the five preceding equations are solved simultaneously by dividing the material into small elements. Then the quantities X , U , D , R , E , and so forth, are evaluated only at the discrete positions and times shown in Figure 3.1. The coordinate quantities X and U are obtained at integral values of j and n , whereas all other quantities pertain to the midcell $(j+\frac{1}{2}, n+\frac{1}{2})$ points. Here the cells are treated as constant strain finite elements (each cell has a constant value of all three principal strains throughout its volume). This derivation contrasts slightly with the finite difference approach normally used, but the resulting equations differ only for cylindrical and spherical flow (see Appendix F).

The discrete values of the flow quantities are obtained from Eqs. (3.1) through (3.4), using the nomenclature of Figure 3.1. Here it is convenient to solve for quantities in the order D , E , R , U , and X . The density is obtained from conservation of mass by dividing the stored value of the cell mass, Z , by the thickness of half time, $t^{n+\frac{1}{2}} = t^n + \frac{1}{2}\Delta t$. The first form of Equation (3.3) is not used here because it can give erroneous results for large density changes; instead, the second form of Equation (3.3) is used:



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FIGURE 3.1 GRID FOR DEPICTING COORDINATES AND TIME INCREMENTS

$$D_{j+\frac{1}{2}}^{n+\frac{1}{2}} = \frac{Z_{j+\frac{1}{2}}}{X_{j+1}^n - X_j^n + \frac{\Delta t^{n+\frac{1}{2}}}{2} (U_{j+1}^n - U_j^n)} \quad (3.7)$$

The energy conservation relation is also used in integral form rather than relying on the differential form of Eq. (3.4). As shown in the second form of Eq. (3.4), the strain energy term is the stress times the volume change.

$$E_{j+\frac{1}{2}}^{n+\frac{1}{2}} = E_{j+\frac{1}{2}}^{n-\frac{1}{2}} + \left(\frac{1}{D_{j+\frac{1}{2}}^{n-\frac{1}{2}}} - \frac{1}{D_{j+\frac{1}{2}}^{n+\frac{1}{2}}} \right) R_{j+\frac{1}{2}}^{n-\frac{1}{2}} + (\Delta E_{j+\frac{1}{2}}^n)_{\text{rad}} \quad (3.8)$$

For correct centering of the equations, the stress quantity here should be R^n obtained by averaging $R^{n-\frac{1}{2}}$ and $R^{n+\frac{1}{2}}$. However, $R^{n+\frac{1}{2}}$ is obtained in the next step; hence, Eq. (3.8) is only the first approximation to the energy. The complete procedure for obtaining energy is described in Section 3.2. The stress is next calculated with a constitutive relation represented by Eq. (3.5). Some of the available constitutive relations are described in Section 4.

The velocity is obtained by a discretization of Eq. (3.1), or equivalently, by using "force equals mass times acceleration": and considering a mass pertaining to the j^{th} coordinate point.

$$U_j^{n+1} = U_j^n - \frac{R_{j+\frac{1}{2}}^{n+\frac{1}{2}} - R_{j-\frac{1}{2}}^{n+\frac{1}{2}}}{(Z_{j+\frac{1}{2}} + Z_{j-\frac{1}{2}})/2} \Delta t^{n+\frac{1}{2}} \quad (3.9)$$

Finally, the Eulerian position of the coordinate is computed from Eq. (3.2)

$$X_j^{n+1} = X_j^n + \frac{1}{2} (U_j^{n+1} + U_j^n) \Delta t^{n+\frac{1}{2}} \quad (3.10)$$

The computations proceed from left to right, one cell and coordinate at a time, updating the flow quantities to the new time $t^{n+\frac{1}{2}}$ or t^{n+1} , as appropriate. This process is continued until the right boundary is reached. Then computations resume at the left for the next time increment.

The foregoing integration method is essentially the leapfrog method of von Neumann and Richtmyer. With this approach the derivatives in the equations of mass, momentum, and energy are correctly centered. That is, each of the conservation relations is replaced by a numerical approximation in which all terms pertain to the same point in time and space. For example, in the momentum equation (3.9), $\partial U/\partial t$ and $\partial R/\partial Z$ are both centered precisely at $(n+\frac{1}{2}, j)$, and therefore, the solution scheme is of second order, although no numerical approximations to $\partial^2 U/\partial t^2$ or $\partial^2 R/\partial Z^2$ are needed.

In the code, the names of quantities are essentially those given above in the discretized equations. The coordinate quantities are $U(J) = U_j^{n+1}$ and $X(J) = X_j^{n+1}$, and the cell quantities are of the form $RHL(J) = R_{j+\frac{1}{2}}^{n+\frac{1}{2}}$. The time step is $DTNH = \Delta t^{n+\frac{1}{2}}$. Hence the coordinate point and the cell to the right are both labeled J , and the midcell quantities at $n+\frac{1}{2}$ and the coordinate quantities at $n+1$ are stored in the arrays. Boundaries between materials are treated in the same fashion as coordinates within a material except that an extra coordinate is provided to permit separation of the layers.

3.2 Pressure-Energy Calculation

A special solution method for obtaining stress and energy simultaneously was necessary to permit use of arbitrarily complex equations of state. The set of equations governing wave propagation includes expressions for pressure as a function of energy and density and for energy as a function of stress and density.

$$P = P(E, \rho) \quad (3.11)$$

$$E = E_0 + \int_0^{\sigma} \frac{\sigma d\rho}{\rho^2} + \Delta E_r \quad (3.12)$$

where ΔE_r is radiant energy. These expressions may be solved simultaneously as in WONDY¹⁶ if the pressure function is linear in energy, by multiple calls to the equation-of-state routine as in PUFF 66,¹⁵ or by extrapolation as in a two-step integration scheme.^{2,17} A combined extrapolation and simultaneous solution method was developed for use in the

current one-step integration scheme of SRI PUFF 8. First we estimate the internal energy at the current step. This energy is used to compute the stress. Then these provisional values of stress and energy, plus derivatives of the pressure, are used to solve simultaneously for the stress and internal energy. The process is described algebraically below: it is implemented in HAFSTEP, the subroutine that computes density and energy and calls HSTRESS for the stress calculation.

The total mechanical stress R and the internal energy E are the variables to be determined. The stress R is defined as

$$R = Q + \sigma = Q + \sigma' + P \quad (3.13)$$

where Q , σ , σ' , and P are the artificial viscous stress, thermodynamic stress, deviatoric stress, and pressure. For the simultaneous solution for R and E , R is presumed to be derivable from the previous value R_1 and the pressure derivatives as follows:

$$R = R_1 + \frac{\partial P}{\partial \rho} \Delta \rho + \frac{\partial P}{\partial E} \Delta E \quad (3.14)$$

Thus only changes in P are considered; changes in Q and σ' are presumed to be small. The derivative $\partial P / \partial E$ is derived analytically from the expression for pressure, while the other derivative is derived from the solution of Eq. (3.14) following the stress determination in the previous time step.

$$\frac{\partial P}{\partial \rho} = \frac{R - R_1 - \frac{\partial P}{\partial E} \cdot \Delta E}{\Delta \rho} \quad (3.15)$$

The two derivatives have approximately the following values:

$$\frac{\partial P}{\partial \rho} = \Gamma E + \frac{C}{\rho_0} \quad (3.16)$$

$$\frac{\partial P}{\partial E} = \Gamma \rho \quad (3.17)$$

where Γ is the Grüneisen ratio, C is the bulk modulus, and ρ_0 is the initial density. The estimate of internal energy E is made by evaluating Eq. (3.2) with the available densities ρ_1 and ρ_2 at the previous and current times, the average of stresses R and R_1 (using Eq. 3.14), and the increment of radiant energy ΔE_r

$$E' = E_1 + 0.5 \left(\frac{1}{\rho_1} - \frac{1}{\rho_2} \right) \left(2R_1 + \frac{\partial P}{\partial \rho} \Delta \rho + \frac{\partial P}{\partial E} \Delta E_r \right) + \Delta E_r \quad (3.18)$$

(This is the actual expression used instead of Eq. (3.8).) With this value of internal energy, HSTRESS is called to compute the new stresses: R' , σ_2 , and P_2 . The simultaneous equations to be solved for the state variables R_2 and E_2 are derived from Eqs. (3.12) and (3.14).

$$E_2 = 0.5 \left(\frac{1}{\rho_1} - \frac{1}{\rho_2} \right) (R_1 + R_2) + E_1 + \Delta E_r \quad (3.19)$$

where R' and E' are the provisional values. The simultaneous solution of Eqs. (3.19) and (3.20) provides the required values of stress and energy. The thermodynamic stress quantities σ and P are not altered but are used as they are computed in HSTRESS.

3.3 Artificial Viscous Stress

The artificial viscous stress is required in finite difference wave propagation calculations to smooth out shock waves so that the entire flow field can be treated by the conservation equations of continuous flow, Eqs. (3.1) through (3.4). The artificial viscous stress (Q) is the difference between the nonequilibrium mechanical stress (R) and the equilibrium thermodynamic stress (σ) given by the constitutive relations. Hence Q represents real stresses occurring in the nonequilibrium states of the shock front. But the basis for computing Q is artificial, depending on the computational cell size and on viscosity coefficients, which are not related to real physical processes.

In SRI PUFF the usual linear and quadratic viscosity forms are provided. The linear form is computed by the equation

$$Q = - C_1 C_s \rho \Delta U \quad (3.21)$$

where C_1 = dimensionless coefficient of linear artificial viscosity,

C_s = sound speed,

and $\Delta U = U_{j+1} - U_j$.

The linear artificial viscosity is similar in form and operation to the standard linear viscosity models used to represent material behavior. However, here, the coefficient C_1 is chosen to provide enough damping to minimize oscillations in the calculations and not to represent the real material viscosity. In the code C_1 is given different values for compressive and rarefaction waves so that less damping can be provided for unloading processes. For compression, useful values are in the range of 0.05 to 0.30; for rarefaction, we have used 0.05.

The quadratic artificial viscosity proposed originally by von Neumann and Richtmyer has the form

$$Q = C_0^2 \rho (\Delta U)^2 \quad (3.22)$$

where C_0^2 is the dimensionless viscosity coefficient, and

$\Delta U = U_{j+1} - U_j$, as before.

The quadratic viscosity is permitted to act only on compressive waves. For normal values of C_0^2 of 3 or 4, the shock front is rapidly spread over three to four cells and then maintains essentially a constant thickness as the wave propagates. Because of the quadratic nature of the expression for Q , very little damping occurs outside the shock front. By contrast, the linear viscosity tends to continue to erode the wave fronts as long as they propagate.

Normally, both linear and quadratic artificial viscosities are used, so the artificial viscous stress Q is the sum of the linear and quadratic terms from Eqs. (3.21 and (3.22). The quadratic viscosity quickly

establishes the shock front thickness. The linear viscosity damps the small oscillations that would otherwise occur near the shock front, but is given a small enough coefficient so that the wave front is not seriously eroded.

3.4 Time-Step Control

For the calculations to proceed in a stable manner, the time increment between cycles must be kept smaller than that given by the Courant-Friedrichs-Lewy condition (see Ref. 2, p. 262). This criterion is simply

$$\Delta t \leq \frac{\Delta X}{C_e} \quad (3.23)$$

where ΔX is the cell size and C_e is the local effective sound speed (defined later).

The criterion means that the time step cannot be so large that the new points are outside the characteristic domain of dependence of the previous points. Referring to Figure 3.1, the new point $(n+1, j-1)$, for which the variables are computed from values at $(n, j-2)$, $(n, j-1)$, and (n, j) , must lie within the domain of dependence or range of waves from those points. This domain is contained between lines with speeds of C_e . A physical interpretation of the requirement is that a wavelet cannot be allowed to proceed from one coordinate point to beyond another in one time step, since this would allow a material point to "see," and be affected by, conditions at material points outside the true domain of dependence. This simple criterion is modified to provide for added safety (the time step used is 80% of the time step at the limit of stability), to allow for the effect of artificial viscosity, and to allow for the influence of high particle velocities.

Artificial viscosity stiffens the material and therefore increases the apparent sound speed, reducing the allowable time step. For linear and quadratic viscosity coefficients (C_1 and C_0^2), Herrmann et al. (Ref. 16, p. 37) derived the following reduction factor F to be applied to the time step:

$$F = \frac{1}{\sqrt{1 + (C_1 + C_2 \cdot |\Delta U|/C_s)^2 + C_1 + C_2 \cdot |\Delta U|/C_s}} \quad (3.24)$$

where C_s is the material sound speed and ΔU is the change in particle velocity between mesh points. To speed the computation by eliminating the square root process, the denominator of Eq. (3.24) is approximated by

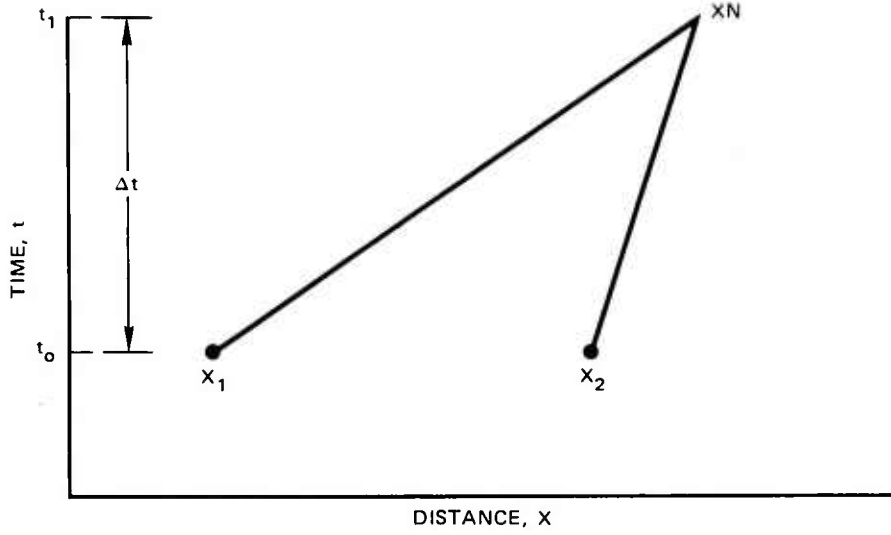
$$\sqrt{1 + C_F^2} + C_F \approx 1 + 0.5 C_F^2 + C_F \quad (3.25)$$

where $C_F = C_1 + C_2 \cdot |\Delta U|/C_s$ because C_F should be a small fraction.

Our experience with radiation deposition computations has indicated that instabilities can arise when the particle velocities get very large. For example, in the vaporized region near the front surface, particle velocities may approach or exceed sound velocities. In such cases the usual stability criterion, $\Delta t = \Delta X/C_s$, is no longer sufficient.

Consider the X, t plot in Figure 3.2. The point X_N is the intersection of a forward-going sound wave from (X_1, t_o) and the cell boundary, which was at (X_2, t_o) . Then

$$X_N = U_2 \Delta t + X_2 \quad (3.26)$$



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FIGURE 3.2 AN X-t PLOT FOR THE TIME STEP COMPUTATION

The time required for a wave to travel from X to X_N , that is, to traverse the cell, is

$$\Delta t = \int_{X_1}^{X_N} \frac{dX}{U + C_s} \quad (3.27)$$

It will be assumed that $U + C_s$ varies linearly from X_1 to X_2 so that

$$U + C_s = U_1 + C_{s1} + \tau(U_2 + C_{s2} - U_1 - C_{s1}) \quad (3.28)$$

where τ goes from 0 to 1. Then $dX = d\tau(X_N - X_1)$ and the integral is

$$\begin{aligned} \Delta t &= (X_N - X_1) \int_0^1 \frac{d\tau}{U + C_s} \\ &= \frac{X_N - X_1}{C_{s2} + U_2 - C_{s1} - U_1} \ln \left(\frac{C_{s2} + U_2}{C_{s1} + U_1} \right) \quad (3.29) \end{aligned}$$

$$= \frac{X_N - X_1}{C_{s2} + U_2 - C_{s1} - U_1} \ln \frac{1+y}{1-y}$$

where

$$y = \frac{C_{s2} + U_2 - C_{s1} - U_1}{C_{s2} + U_2 + C_{s1} + U_1}$$

The series expansion of the logarithm term is $2(y + y^3 + \dots)$. Only the first term is used here, giving

$$\Delta t = \frac{2(X_N - X_1)}{C_{s2} + U_2 + C_{s1} + U_1} = \frac{2(X_2 + U_2 \Delta t - X_1)}{C_{s2} + U_2 + C_{s1} + U_1} \quad (3.30)$$

When the Δt terms are collected on the left side, the result is

$$\Delta t = \frac{2(X_2 - X_1)}{C_{s2} + C_{s1} + U_1 - U_2} \quad (3.31)$$

If the value of Δt computed from this equation is negative, the two paths do not intersect and Δt can be set to an arbitrarily large value. The criterion used in the program is a simple combination of this equation and the safety factors, (0.8 and F), presented earlier:

$$\Delta t = 0.8 \left(\frac{2(X_2 - X_1) F}{C_{s2} + C_{s1} + U_1 - U_2} \right) \quad (3.32)$$

The time-step computations are begun in HSTRESS, continued in HYDRO, and completed in the main program.

Note that an effective sound speed accounting for artificial viscosity and particle velocity is

$$C_e = \frac{C_{s2} + C_{s1} + U_1 - U_2}{2F} \quad (3.33)$$

The sound speed C_s is required only to control the time step. The analytical expression for sound speed is

$$C_s^2 = \left(\frac{\partial \sigma}{\partial \rho} \right)_{\bar{S}} = \left(\frac{\partial P}{\partial \rho} \right)_{\bar{S}} + \left(\frac{\partial \sigma'}{\partial \rho} \right)_{\bar{S}} \quad (3.34)$$

where σ, σ' are the stress and deviator stress in the direction of propagation and \bar{S} = entropy; as a subscript it means that the derivative is taken at constant entropy. The elastic or low stress approximation to the sound speed of compressional waves is

$$C_s^2 = \frac{C}{\rho} + \frac{4}{3} \frac{G}{\rho} \quad (3.35)$$

where C is the bulk modulus and G is the shear modulus.

In the PUFF code the sound speed is used only to determine the permissible size of the next time step and to compute the artificial viscosity. The minimum time is governed by maximum speed, the speed of a small elastic unloading wave; hence, expressions (3.34) or (3.35) can be evaluated to give an upper bound on the sound speed. Thus $\partial \sigma' / \partial \rho$ or G/ρ is computed from the largest shear modulus associated with the current stress, thereby neglecting that the material may be at yield so the effective modulus is actually zero.

At high stress, the bulk modulus is expected to increase significantly, so the derivative $\partial P / \partial \rho$ should be evaluated instead of using C/ρ . A procedure for numerically evaluating the partial derivative was developed for the program. The first law of thermodynamics for an isentropic ($d\bar{S} = 0$) process is

$$dE = -PdV = -Pd\left(\frac{1}{\rho}\right) \quad (3.36)$$

The usual rule for partial differentiation provides

$$dE = \left(\frac{\partial E}{\partial P} \right)_{\rho} dP + \left(\frac{\partial E}{\partial \rho} \right)_P d\rho \quad (3.37)$$

From these two equations and the chain rule

$$- \left(\frac{\partial E}{\partial \rho} \right)_P = \left(\frac{\partial E}{\partial P} \right)_{\rho} \left(\frac{\partial P}{\partial \rho} \right)_E \quad (3.38)$$

the required derivative is obtained:

$$\frac{dP}{d\rho} = \left(\frac{\partial P}{\partial \rho} \right)_E + \frac{P}{\rho^2} \left(\frac{\partial P}{\partial E} \right)_{\rho} \quad (3.39)$$

The derivative $dP/d\rho$ was taken along an isentrope and therefore is properly written $(\partial P/\partial \rho)_{\bar{S}}$.

As an example of the sound speed calculation, the derivative is obtained for the Mie-Grüneisen equation with $\Gamma\rho$ a constant.

$$P = P_H \left(1 - \frac{\Gamma\mu}{2} \right) + \Gamma\rho E \quad (3.40)$$

where

$$P_H = C_{\mu} + D_{\mu}^2 + S_{\mu}^3, \text{ the pressure on the Hugoniot}$$

C, D, S = material constants with units of bulk moduli

Γ, Γ_0 = the current and initial values of Grüneisen's ratio

$\mu = \rho/\rho_0 - 1$, a strain.

Then the expression for sound speed, derived from Eq. (3.39) is

$$\begin{aligned}
c_s^2 = \left(\frac{\partial P}{\partial \rho} \right)_{\bar{s}} + \frac{4G}{3\rho} = \frac{C+2D\mu + 3S\mu^2}{\rho_o} \left[1 - \frac{\Gamma_o}{2} \left(1 - \frac{\rho_o}{\rho} \right) \right] \\
+ P_H \left(- \frac{\Gamma_o \rho_o}{2\rho^2} \right) + \frac{P}{\rho^2} \Gamma_o \rho_o + \frac{4G}{3\rho}
\end{aligned}
\tag{3.41}$$

3.5 Outline of Subroutines

The subroutines that control the wave propagation calculations and contain the equations developed in this section are HYDRO, HAFSTEP, and HSTRESS. HYDRO contains the position and particle velocity calculations, whereas HAFSTEP has the density and energy calculations as well as the simultaneous pressure-energy solution. HSTRESS contains the artificial viscous stress (Q) and mechanical stress (R) equations, but is mainly a switching routine for selecting appropriate constitutive relations for each material. HYDRO and HAFSTEP are described below. Because of the involvement with constitutive relations, HSTRESS is described in Section 4.

HYDRO. For each call to HYDRO from SRI PUFF, a calculation is made for all cells and coordinates which are currently active. HYDRO contains separate paths for the several coordinate conditions provided. The coordinate conditions and their indicators are:

Normal (N) - interior coordinate point (within a layer of material).

Interface (L,R) - left and right coordinate points at an interface between layers.

Separated interface (S) - right coordinate point at a separated interface. First and last coordinates are treated by this path.

Mirror or reflective boundary (M) - a constant-velocity boundary (arbitrary velocity histories should be imposed by modifying this path).

Pressure boundary (P) - first and last boundaries may have a pressure history with a shock front and exponential decay, or a history provided by a series of pressure and time values.

Infinite boundary (I) - first or last boundaries are treated as if a mass of the same material continued indefinitely to the left or right past the actual first or last coordinate points (implemented only for planar case).

The path to be taken for each coordinate is determined by an indicator array, H(J,2). Values of the indicator are given above in parentheses following the path title.

In each path a call is first made to HAFSTEP to compute density, energy, and stress; then the new coordinate's position and velocity are computed. A test is made for spallation at the end of the interface path and for recombination in the separated path.

At the end of HYDRO, brief calculations are made to determine the largest J value (JSTAR) for which EDITs should be printed and to determine the stable time step for the next cycle.

HAFSTEP. The HAFSTEP subroutine is called by HYDRO for each cell and each time step to compute the midcell quantities of density, energy, and stress. To preserve accuracy in the stress calculations, the time step may be divided into small intervals (subcycles) for calculating the midcell quantities. Not more than 1% density change is permitted in any subcycle. This subcycling feature is important for constitutive relations in which internal energy is important and for relations based on differentials.

The internal energy is estimated using Eq. (3.18) and then HSTRESS is called for the stress calculation. Following the completion of HSTRESS, the final solution is made for energy and mechanical stress (R) from Eqs. (3.19) and (3.20). The derivatives $\partial P/\partial E$ used to determine the energy estimate are computed before returning to HYDRO.

4. CONSTITUTIVE RELATIONS

The constitutive relations provide the stress as a function of density, strains, internal energy, and other quantities. This section describes the common constitutive relations and outlines the available constitutive models. The subroutine HSTRESS, which selects the correct constitutive subroutine for each material, is also described.

4.1 Standard Constitutive Models

In the standard constitutive relations, the stress tensor is separated into a pressure and a stress deviator tensor. The pressure is the average stress

$$P = 1/3 \sum_i \sigma_{ii} \quad (4.1)$$

and the stress deviator elements are

$$\sigma'_{ij} = \sigma_{ij} - P\delta_{ij} \quad (4.2)$$

where σ_{ij} are stress tensor elements and δ_{ij} is the Kronecker delta. The pressure is usually presented as a function of density and internal energy. The deviator stress is calculated by elastic, plastic relations, which may include thermal softening, rate-dependent effects, and work hardening. The standard pressure and deviator models are presented in the following sections.

4.1.1 Standard Pressure Models

The pressure is computed from a simplified form of an equation of state, the locus of all possible thermodynamic equilibrium states for a substance. Each state is a set of values of the following thermodynamic quantities: stress tensor, specific volume, entropy, specific internal

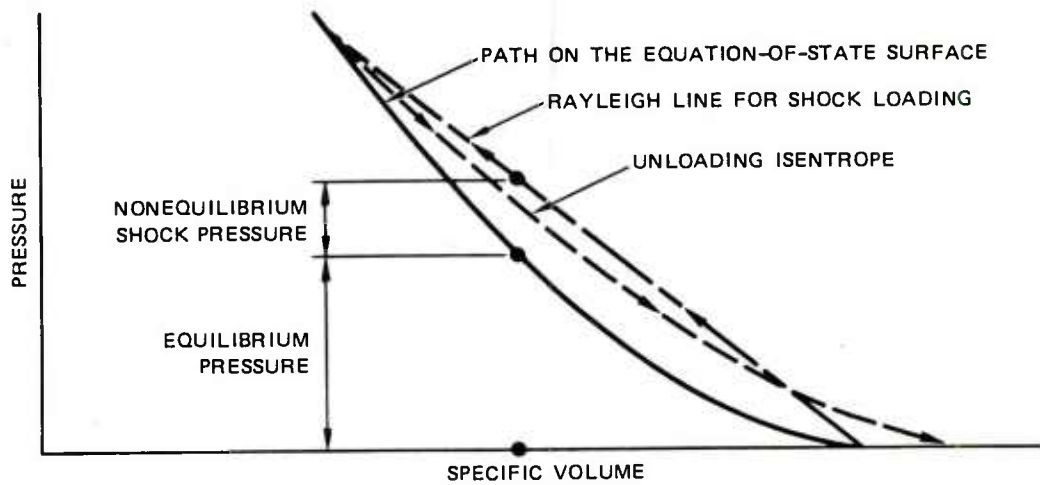
energy, and temperature. In the simplified equation of state used here and in most wave propagation codes, the only variables considered are pressure (the deviator components of stress are treated separately), specific volume (V) or density ($\rho = 1/V$), and internal energy (E). The equation of state is then

$$P = P(E, V) \quad (4.3)$$

which defines a surface or locus of points in energy-pressure-volume space.

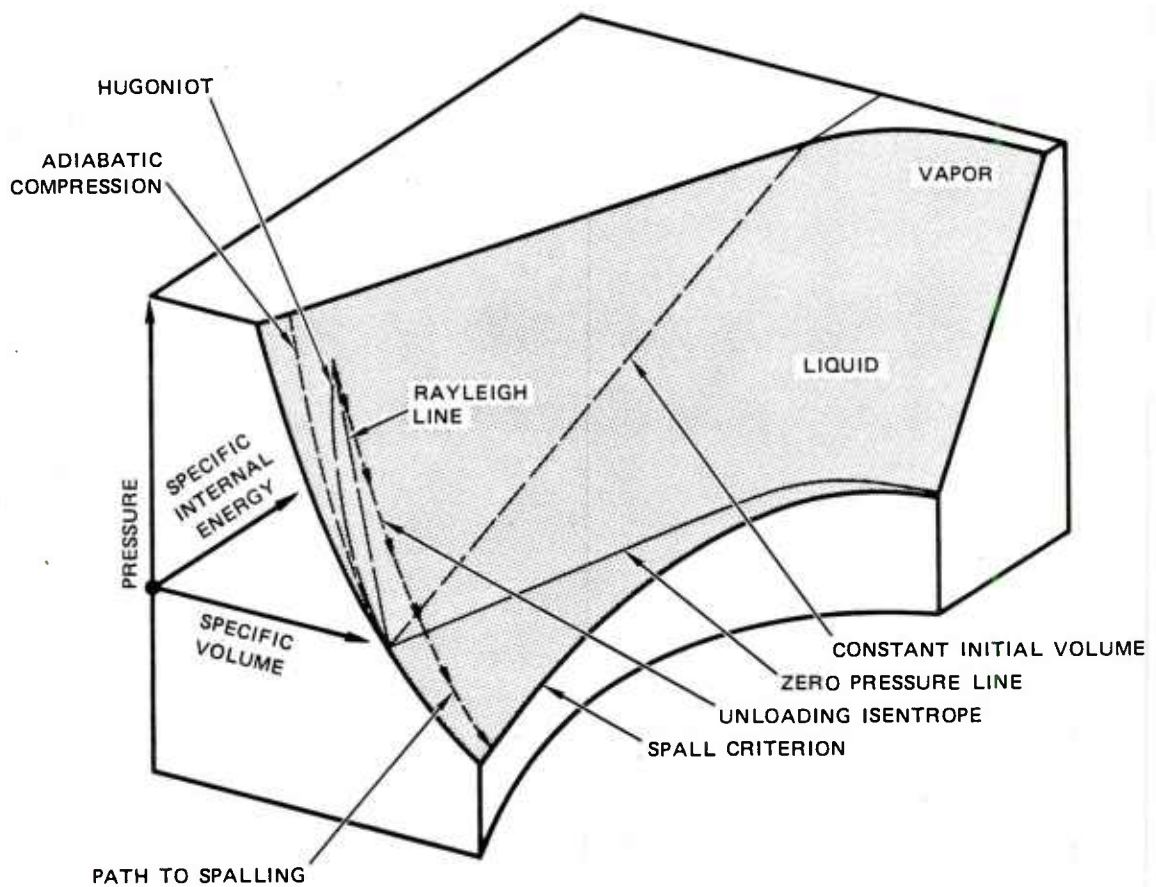
An equation of state represents equilibrium states. Therefore, as a material undergoes gradual changes, such as heating or compression, the successive states describe a path on the equation-of-state surface. If the material is compressed by passing through a steady-state shock front, the initial and final states lie on the P - V - E surface. These initial and final states are connected by a straight line, the Rayleigh line, which does not lie on the surface, but above the P - V - E surface. The states of transition within a shock front are not states of thermodynamic equilibrium. The equation of state describes the material behavior in solid, liquid, and gaseous phases. The standard pressure model gives a detailed treatment of the solid behavior, but the other phases are described by approximate relations without specific determination of the particular phase.

First, we examine the paths taken on the equation-of-state surface by material under shock loading. Shock experiments lead to the determination of a Hugoniot or Rankine-Hugoniot equation of state that is represented by one curve on the equation-of-state surface. This line is the locus of final states that can be obtained by a steady-state shock transition from a given initial state. The pressure-volume path taken by the material during the shock and a subsequent unloading is shown in Figure 4.1. The shock path follows a Rayleigh line, to a point on the equation-of-state surface. Pressures on the Rayleigh line can be considered to be decomposed into an equilibrium pressure represented



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FIGURE 4.1 PRESSURE PATHS FOR SHOCK LOADING AND UNLOADING OF A MATERIAL



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FIGURE 4.2 ENERGY-PRESSURE-VOLUME (E-P-V) SURFACE FOR A SOLID MATERIAL

by a point on the equation-of-state surface plus a nonequilibrium pressure component. In code calculations the equilibrium pressure is computed from the equation of state, and the nonequilibrium component is computed as the artificial viscous stress. Figure 4.2 shows the Rayleigh line and unloading isentrope on the equation-of-state surface with a Hugoniot curve. During the shock loading the internal energy increases, as indicated in this figure. Less internal energy is used in the elastic recovery on unloading down the isentrope; hence the unloading does not coincide with loading, and the final, unloaded state is warmer than the initial state and at a larger specific volume (for materials that expand during heating).

As a reminder of the role of stress in the compression of the solid, consider the stress-volume Hugoniot of Figure 4.3. Here only the stress component in the direction of propagation is shown. During compression, the stress is greater than the pressure; on unloading, the stress decreases rapidly to yielding and then follows a stress isentrope below the pressure isentrope.

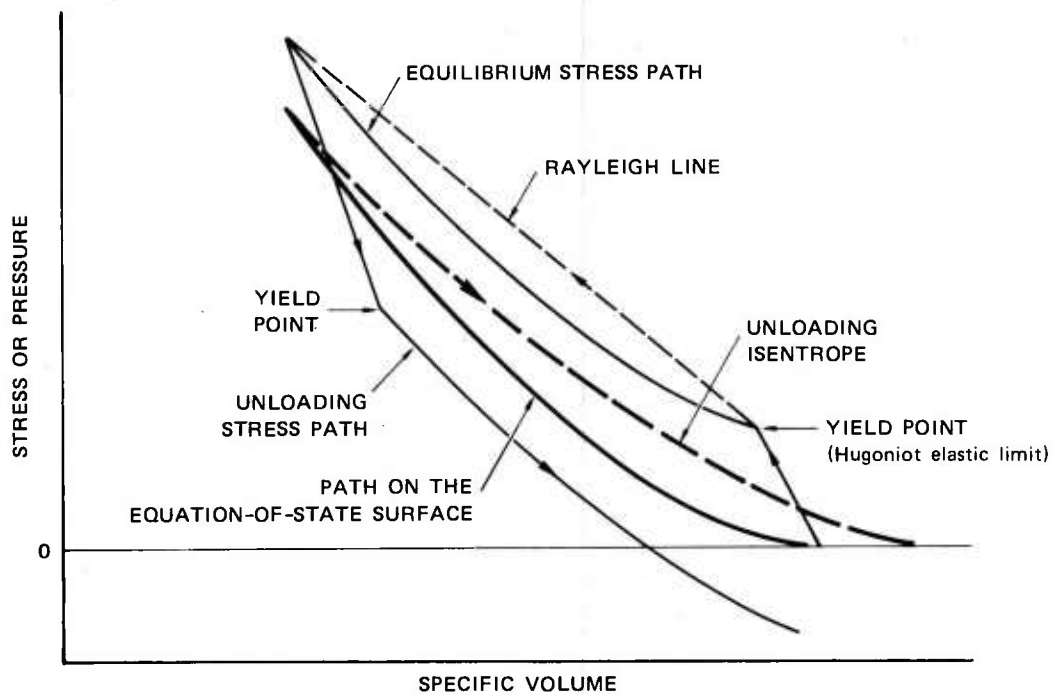
Several other lines of interest are shown in Figure 4.2. The adiabatic compression path is followed by a rapid but nonshock loading in which no heat conduction occurs. The unloading isentrope is a similar, equilibrium process without heat conduction. The zero pressure line is the locus of points obtained by simply heating the material without external mechanical confinement. Heating increases the internal energy, and thermal expansion occurs. For small increases in internal energy, the zero pressure curve describes the usual expression for volumetric thermal expansion

$$V = V_0 (1 + \alpha \Delta\theta) \quad (4.4)$$

where V_0 = the initial specific volume

α = the volumetric thermal expansion coefficient

$\Delta\theta$ = the change in temperature.



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FIGURE 4.3 LOADING AND UNLOADING PATHS FOR PRESSURE AND FOR STRESS IN THE DIRECTION OF PROPAGATION

The zero pressure curve becomes asymptotic to the line described by

$$\begin{cases} E = \text{vaporization energy} \\ P = 0 \end{cases}$$

for large V .

The spall path is shown only to indicate the direction taken in tension. Spall, or fracture, is a rate-dependent process that generally depends on the stress tensor (not simply the pressure) and on the internal energy. Regions where the energy is high enough that the material is liquid or vapor are to the right in Figure 4.2. The vapor region extends indefinitely to the right.

The equation-of-state surface depicted in Figure 4.2 is an idealized form that is applicable to a material that does not experience solid phase changes or other phenomena that lead to regions of negative curvature in the P - V plane. While this surface represents the material behavior qualitatively, only certain regions of the surface are well understood quantitatively. The best-understood region is in the vicinity of the Hugoniot because of the availability of experimental data along that curve. The least-understood regions are those near spalling and those at high energies and to the right of $V = V_0$.

Having outlined some properties of the equation of state, we now introduce the analytical forms used in the standard pressure model. In the model two expressions are used: one for compression to states with density greater than the initial density and one for extended states.

The equation used to describe compression is the Mie-Grüneisen equation

$$P - P_{\text{REF}} = \frac{\Gamma(V)}{V} (E - E_{\text{REF}}) \quad (4.5)$$

where

P_{REF} and E_{REF} = a point on some reference curve at the same specific volume V

$\Gamma(V)$ = the Grüneisen ratio.

Equation (4.5) was derived by assuming that Γ is a function of V only. Equation (4.5) provides a means for extending the information of a known P-V relation (such as the Hugoniot) to other values of internal energy. Because the Hugoniot is the P-V relation that is most likely to be known, the computations are constructed so that the Hugoniot is the reference curve used. The Hugoniot P-V equation is presumed to be in the form

$$P_H = C\mu + D\mu^2 + S\mu^3 \quad (4.6)$$

where

$$\mu = \frac{\rho}{\rho_0} - 1 = \frac{V_0}{V} - 1$$

C = bulk modulus

D, S = coefficients with the units of moduli.

The internal energy along the Hugoniot is

$$E_H = \frac{1}{2} P_H (V_0 - V_H) \quad (4.7)$$

Equation (4.7) assumes that the initial internal energy is zero and that the Hugoniot is concave upward throughout. In general, the latter assumption excludes consideration of changes of state. Although the relation is strictly true only for the stress Hugoniot, not the pressure Hugoniot, little inaccuracy is introduced by this approximation. With the aid of Eqs. (4.6) and (4.7), the Mie-Grüneisen equation takes the following form in the program

$$P = (C\mu + D\mu^2 + S\mu^3) \left(1 - \frac{\Gamma\mu}{2}\right) + \Gamma\rho E \quad (4.8)$$

When material is held at a particular volume and heated (internal energy is added), it goes through states that are straight lines on the equation-of-state surface. This indicates that, for constant volume V_1 , the analytical equations for the surface have the form

$$E = A(V_1) \cdot P \quad (4.9)$$

where $A(V_1)$ = a function of V_1 only. The equation-of-state surface is constructed simply by translating the Hugoniot curve parallel to itself to higher energy states. The line $V = V_0$ is the boundary between the Mie-Grüneisen equation and an expansion equation.

The expansion equation, which is similar to that used in PUFF 66, must meet four requirements. It must:

- Join smoothly to the Mie-Grüneisen equation along $V = V_0$.
- Expand like $PV = E(\gamma - 1)$ at large expansions (like a perfect gas).
- Provide a linear relation between P and E for constant V .
- Account for the partition of internal energy into components for kinetic energy and for vaporization energy.

The equation that satisfies these requirements is

$$P = \rho \Gamma_e \left(E - E_e \left\{ 1 - \exp \left[N \left(1 - \frac{\rho_{so}}{\rho} \right) \frac{\rho_{so}}{\rho} \right] \right\} \right) \quad (4.10)$$

where

ρ, ρ_{so} = current and initial density

$\Gamma_e = H + (\Gamma_0 - H) \left(\frac{\rho}{\rho_{so}} \right)^n$, the effective Grüneisen ratio for expanded states.

$H = \gamma - 1$ for expansion at low densities and γ is the polytropic gas exponent

$E_e = E_s$ in general

$= E_s \left[1 + \ln \left(\frac{E}{E_s} \right) \right]$ for $E > E_s$ and $n \neq 0.5$

E_s = sublimation energy for metals

= incipient vaporization energy for mixed-oxide ceramics.

n = a constant, usually 0.5 for metals, 1.67 for mixed-oxide ceramics

$$N = \frac{C}{\Gamma_o \rho_{so} E_e} \text{ for } \Gamma_1 = 0$$

$$= \frac{C}{\Gamma_o \rho_{so} E_e} + \frac{\text{Min}(E, E_s)}{E_e} \left[\frac{\Gamma_1}{\Gamma_o} + n \left(\frac{H}{\Gamma_o} - 1 \right) \right] \text{ for } \Gamma_1 \neq 0$$

$\Gamma = \Gamma_o + \Gamma_1 \mu$, the effective Grüneisen ratio for $\rho \geq \rho_{so}$

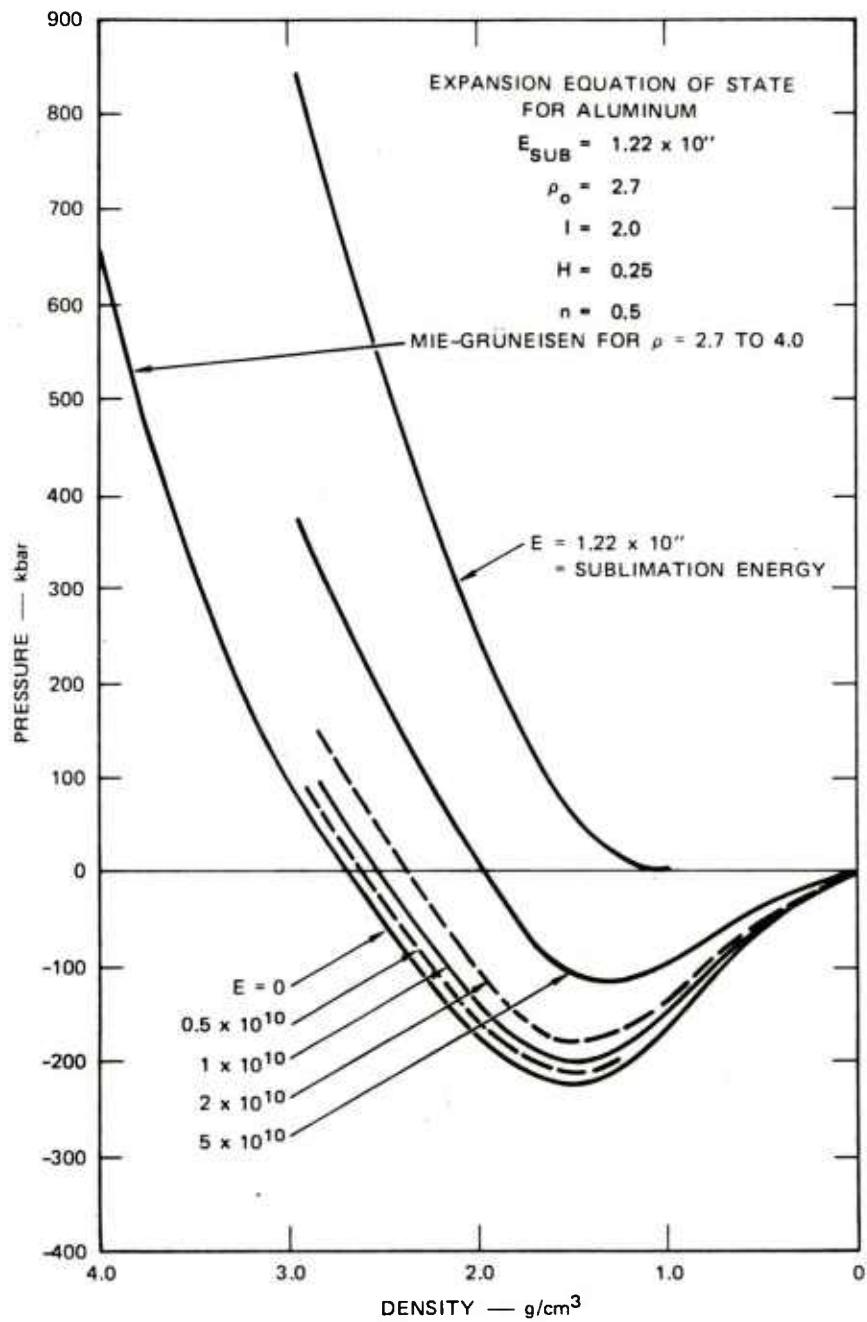
C = coefficient in Eq. (4.6), the bulk modulus at low pressures.

The present expansion equation differs from that in PUFF 66 because of improvements in N to provide continuity of $\partial P / \partial V$ at $\rho = \rho_{so}$ with the Mie-Grüneisen relation and to provide a variable vaporization energy, which seems to be required for some materials.

As an indication of the shape of the P-V-E surface generated by the expansion equation, several pressure-volume curves are given in Figure 4.4 for aluminum. Note that the curves are all continuous at $\rho = 2.7$, the density at which the joint to the Mie-Grüneisen equation occurs. The expansion equation permits a large tensile pressure excursion at low internal energies and then, for decreasing densities, gradually takes on the form of a perfect gas law. Figure 4.5 exhibits the modified PUFF expansion equation (typical of a mixed-oxide ceramic) in P-V-E space for compressive states. The initial solid (SO), solid melt (SM), and liquid boil (LB) points are labeled.

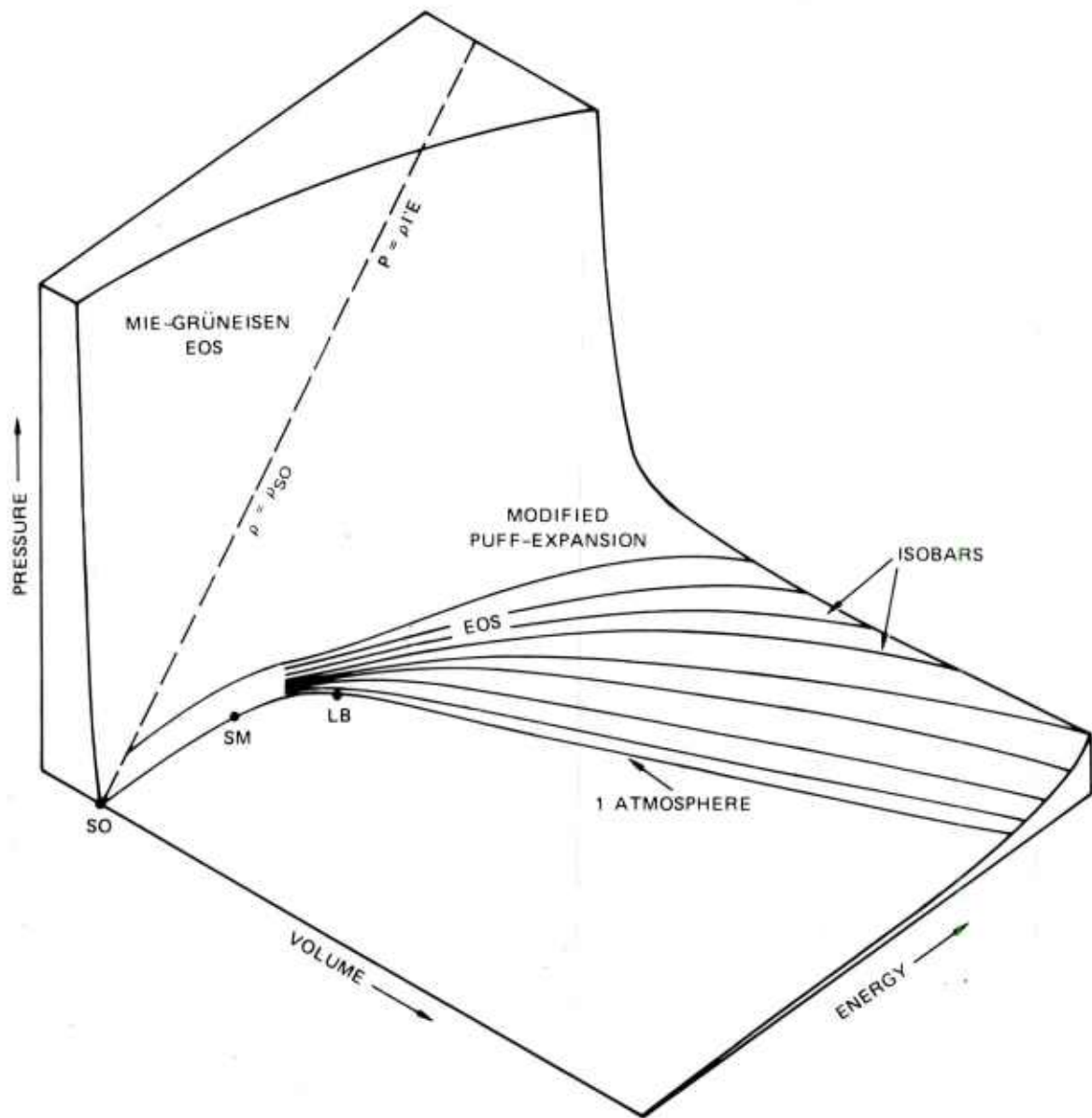
Many of the equation-of-state parameters are available in standard handbooks. For example, C is the isentropic bulk modulus at low pressures. According to Rice, McQueen, and Walsh,³⁷ D in Eq. (4.6) may be estimated from $D = \Gamma_o C$. The sublimation energy, E_s , is the difference between the internal energy of the solid material at ambient conditions and the internal energy of the fully expanded vapor at a temperature of absolute zero. This quantity is referred to as ΔH_{fo}^0 in the JANAF tables³⁸ for the gas state.

The Grüneisen ratio Γ may be estimated from thermal expansion data, using the relation



GA-6586-24

FIGURE 4.4 PRESSURE-VOLUME RELATIONS AT CONSTANT INTERNAL ENERGY FOR AN ALUMINUM



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FIGURE 4.5 SKETCH OF MIE-GRÜNEISEN AND MODIFIED PUFF-EXPANSION EQUATION-OF-STATE MODEL

$$\Gamma = \frac{C\alpha}{\rho_{so} C_p} \quad (4.11)$$

where

α = the volumetric thermal expansion coefficient

C_p = the specific heat at constant pressure.

The result from Eq. (4.11) should be relied on only if all quantities pertain to the same density, pressure, and temperature. For many materials, Γ lies between 1.0 and 2.0; if internal energy is not important in the problem, an estimate can be made in this range.

The Hugoniot form traditionally used with PUFF calculations is the three-term expansion in Eq. (4.6). At large strains this form has the disadvantage that it does not have a physically reasonable behavior, especially if some of the coefficients are negative. Two alternative Hugoniot forms are discussed here: the Murnaghan form and the linear $U_s - U_p$ relation. Both are provided as options in the standard pressure model.

The Murnaghan equation for the Hugoniot results from an integration of the following linear expression for bulk modulus.

$$-V \left(\frac{\partial P}{\partial V} \right)_H = a + bP \quad (4.12)$$

where the derivative is taken along the Hugoniot, V is the specific volume, P is pressure, and a and b are constants. On integration of Eq. (4.12), the Hugoniot pressure is obtained in the Murnaghan form

$$P_H = \frac{a}{b} \left[\left(\frac{V_0}{V} \right)^b - 1 \right] \quad (4.13)$$

This form has the distinct advantage over (4.6) in always increasing monotonically. Hence, if it is used for pressures somewhat above the data on which the fitting parameters a and b are based, the computed pressures should be physically reasonable. The data from many materials

have been shown to fit this Murnaghan form well. The parameters a and b can be easily related to the coefficients in Eq. (4.6) by taking the derivatives of (4.6) with respect to volume and comparing terms. From Eq. (4.6)

$$-V \left(\frac{\partial P}{\partial V} \right)_H = C + \mu(C + 2D) + \mu^2(3S + 2D) + \dots \quad (4.14)$$

Eq. (4.12) can be expanded to

$$-V \left(\frac{\partial P}{\partial V} \right)_H = a + b(C\mu + D\mu^2 + S\mu^3) \quad (4.15)$$

Therefore

$$a = C \quad (4.16)$$

$$b = 1 + 2D/C$$

Another estimate of b is obtained from the Rice, McQueen, and Walsh³⁷ relation $\Gamma = D/C$.

Then

$$b = 1 + 2\Gamma \quad (4.17)$$

For many solids the value of b is approximately 5.

Shock wave data are often presented in the form of a linear relation between shock velocity (U_s) and particle velocity (U). The basic relation is

$$U_s = C_L + S_L U \quad (4.18)$$

where C_L and S_L are parameters determined by the fit to data. For a material with no deviator stresses, the pressure from Eq. (4.18) is

$$P_H = \rho_o U U_s = \rho_o (C_L U + S_L U^2) \quad (4.19)$$

Next we replace the velocities by using the expression for the conservation of mass across a shock front

$$\frac{\rho}{\rho_o} = \frac{U_s}{U_s - U} \quad (4.20)$$

and a Lagrangian strain ϵ

$$\epsilon = 1 - \rho_o/\rho \quad (4.21)$$

By combining the foregoing four equations, we determine the Hugoniot pressure as a function of strain

$$P_H = \frac{\rho_o C_L^2 \epsilon}{(1 - S_L \epsilon)^2} \quad (4.22)$$

This is the form used in calculations. By an expansion of the term in Eq. (4.22) and comparison of coefficients with those in Eq. (4.6), it can be shown that

$$S_L = \frac{1}{2} \left(\frac{D}{C} + 1 \right) \quad (4.23)$$

$$C_L = \sqrt{\frac{C}{\rho_o}} \quad (4.24)$$

From Eq. (4.23) and the standard value of 2 for $\Gamma = D/C$, it is expected that S_L is approximately 1.5. The value of C_L is simply the bulk sound speed at low pressures.

4.1.2 Standard Deviator Stress Model

The deviator stress is the part of the stress tensor that arises because of the resistance of the material to shearing deformation. In PUFF the standard model for deviator stresses accounts for elastic response, plastic flow, work hardening, and thermal softening. The yield strength that governs plastic flow can be either of the Mises or Coulomb types. Here the relations are developed in a general form applicable

to planar, cylindrical, or spherical flow. More advanced deviator models are found in Appendix G. Simplified forms specifically applicable to planar, cylindrical, and spherical flow are in Appendix F.

Elastic Relations. The elastic relations between stress and strain are cast in the following form

$$\sigma'_{ij} = 2G \left(\epsilon_{ij}^E - \frac{\delta_{ij}}{3} \sum_{\ell} \epsilon_{\ell\ell}^E \right) \quad (4.25)$$

$$P = C \sum_{ii} \epsilon_{ii} \quad (4.26)$$

Here, σ'_{ij} and ϵ_{ij}^E are the deviatoric stress and elastic strain in the ij direction, G is the shear modulus, δ_{ij} is the Kronecker delta, P is pressure, and C is the bulk modulus. For the elastic case, $\epsilon_{ij} = \epsilon_{ij}^E$, all the strain is elastic. But Eqs. (4.25) and (4.26) are also applicable to the plastic case where the strain increments are separated into elastic and plastic components.

$$d\epsilon_{ij} = d\epsilon_{ij}^E + d\epsilon_{ij}^P \quad (4.27)$$

where $d\epsilon_{ij}$ is the total strain increment and $d\epsilon_{ij}^P$ is the plastic strain increment. For convenience, the terms in the parentheses of Eq. (4.25) can be named a deviator strain defined as follows:

$$\epsilon'_{ij} = \epsilon_{ij}^E - \frac{\delta_{ij}}{3} \sum_{\ell} \epsilon_{\ell\ell}^E \quad (4.28)$$

Then Eq. (4.25) becomes

$$\sigma'_{ij} = 2G \epsilon'_{ij} \quad (4.29)$$

Plastic Relations. The Reuss plasticity relations or "incremental plasticity with an associated flow rule" are considered here first. Modifications to treat Coulomb friction are described later. Yield occurs when the effective stress reaches the yield strength. The effective stress is

$$\bar{\sigma} = \sqrt{\frac{3}{2}(\sigma'_{ij} \sigma'_{ij})} \quad (4.30)$$

where the repeated subscripts indicate summation. The yield criterion is

$$\bar{\sigma} = Y \quad (4.31)$$

where Y is the current yield strength. The Reuss flow rule indicates that the deviator stress in any direction is proportional to the plastic strain in that direction:

$$d\epsilon_{ij}^P = \sigma'_{ij} d\lambda \quad (4.32)$$

where $d\lambda$ is a proportionality constant. Now we define a scalar plastic strain quantity as follows:

$$d\bar{\epsilon}^P = \sqrt{\frac{2}{3} d\epsilon_{ij}^P d\epsilon_{ij}^P} \quad (4.33)$$

As before, the repeated subscripts indicate summation. Now we square Eq. (4.32) and make use of the definitions of $\bar{\sigma}$ and $d\bar{\epsilon}^P$. Then

$$d\bar{\epsilon}^P = \frac{2}{3} \bar{\sigma} d\lambda \quad (4.34)$$

Combining this definition with Eq. (4.32), we find that

$$d\epsilon_{ij}^P = \sigma'_{ij} \frac{3d\bar{\epsilon}^P}{2\bar{\sigma}} \quad (4.35)$$

To obtain a solution for an increment of strain, we compute first the stress that would occur if the strain were entirely elastic, that is,

$$\sigma_{ij}^N = 2G \left(\epsilon_{ij0}^E + \Delta\epsilon_{ij}^E \right) = 2G \left(\epsilon_{ij}^E + \Delta\epsilon_{ij}^P \right) \quad (4.36)$$

where

- ϵ'_{ijo}^E = the elastic deviator up to the current strain step
- $\Delta \epsilon'_{ij}$ = the total deviator strain increment
- ϵ'_{ij}^E = the elastic deviator strain after the current increment
- $\Delta \epsilon'_{ij}^P$ = the plastic strain increment.

The second equality in Eq. (4.36) is obtained by using Eq. (4.27) to decompose $\Delta \epsilon'$ and by adding $\epsilon'_{ijo}^E + \Delta \epsilon'_{ij}^E$ to obtain ϵ'_{ij}^E . Quantities ϵ'_{ij}^E and $\Delta \epsilon'_{ij}^P$ can both be replaced by stress quantities through the use of Eq. (4.29) and Eq. (4.35). Then,

$$\sigma'_{ij}^N = \sigma'_{ij} (1 + 3Gd\bar{\epsilon}^P/\bar{\sigma}) \quad (4.37)$$

If both sides of Eq. (4.37) are squared and a quantity $\bar{\sigma}^N$ is introduced in analogy to the definition of $\bar{\sigma}$, then we obtain

$$\bar{\sigma}^N = \bar{\sigma}(1 + 3Gd\bar{\epsilon}^P/\bar{\sigma}) \quad (4.38)$$

Here, $\bar{\sigma} = Y$.

Combining Eqs. (4.37) and (4.38) yields a solution for σ'_{ij}

$$\sigma'_{ij} = \sigma'_{ij}^N \frac{\bar{\sigma}}{\bar{\sigma}^N} \quad (4.39)$$

Then, the elastic strain can be obtained from Eq. (4.39) and the effective plastic strain from Eq. (4.38)

$$d\bar{\epsilon}^P = \frac{\bar{\sigma}^N - \bar{\sigma}}{3G} \quad (4.40)$$

and finally, each component of plastic strain is found from Eq. (4.32).

The preceding process is especially appropriate for perfect plasticity where Y is constant. The equations are appropriate for steps from one plastic state to another or from an elastic state to a plastic state.

When Coulomb friction is introduced, the preceding equations for Mises plasticity are modified slightly. The fundamental relation provides a shear yield stress τ_c , which is a function of a cohesion c , normal stress σ_N , and the angle of internal friction ϕ

$$\tau_c = c + \sigma_N \tan \phi \quad (4.41)$$

Following Terzaghi,³⁹ this expression is transformed to

$$\sigma_1 = 2c\sqrt{N_\phi} + \sigma_3 N_\phi \quad (4.42)$$

where $N_\phi = \tan^2(45^\circ + \phi/2)$; and σ_1 and σ_3 are the most and least compressive principal stresses. In the derivation we consider that yielding has no effect on volume change (a Coulomb-without-dilation model). Instead of using Eq. (4.42), which is not symmetric because the intermediate principal stress is absent, we introduce the expression of Drucker and Prager⁴⁰

$$\sqrt{J'_2} = k + 3\alpha P \quad (4.43)$$

where J'_2 is the second invariant of the stress deviator tensor, and k and α are constants. Replacing J'_2 by the effective stress $\bar{\sigma} = \sqrt{3J'_2}$, we can obtain the following form for Eq. (4.43)

$$\bar{\sigma} = \frac{3c\sqrt{N_\phi} + \frac{3}{2}(N_\phi - 1)P}{1 + N_\phi/2} \quad (4.44)$$

The constants k and α have been replaced by c and N_ϕ by equating Eqs. (4.42) and (4.43) for the case $\sigma_2 = \sigma_3$. The individual deviator stresses are then obtained from Eq. (4.39).

Work Hardening. A linear work hardening is assumed in the following form:

$$Y = Y_o + Y_D |\Delta\rho| \quad (4.45)$$

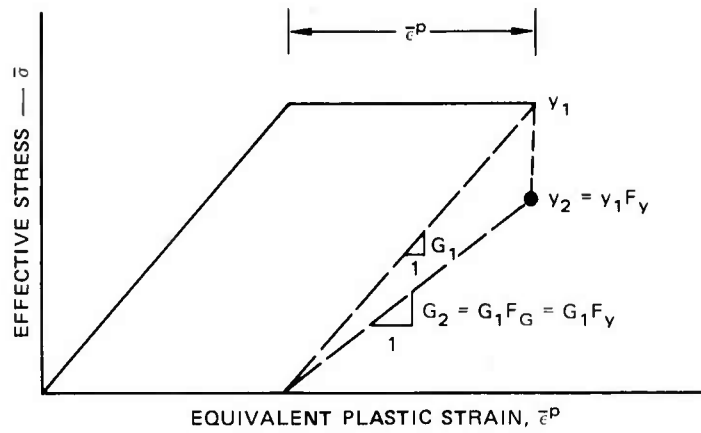
where Y_D is a work-hardening coefficient with the units of $\text{dyn/cm}^2/(\text{g/cm}^3)$. This form is used mainly for historical reasons because it was present in PUFF 66. The input value of Y_D is discussed in Section 5.5. The present formulation is satisfactory for planar flow in which all strain is related to density changes. More appropriate work-hardening processes for other flows are discussed in Appendix G.

Thermal Softening. Material that is heated to an internal energy near melting generally loses considerable strength. In PUFF, thermal softening is permitted to reduce both the yield strength and the shear modulus of a material. Physically each of these parameters probably reduces as a different function of the temperature. Figure 4.6 shows stress-strain relations for two possible thermal softening relations. In each case, it is assumed that the material has been loaded through yielding to the point labeled Y_1 and then heated sufficiently to produce a decrease in yield and modulus. For the case where the thermal softening functions F_Y and F_G for both yield Y and modulus G are equal, complete elastic unloading from either point Y_1 or point Y_2 would reach the same value of shear strain; hence no change in plastic strain is involved. However, when F_Y is not equal to F_G , some adjustment occurs in $\bar{\epsilon}^P$, as shown. When F_G is greater than F_Y , there is an apparent increase in $\bar{\epsilon}^P$, although no strain has actually occurred in proceeding from point Y_1 to point Y_2 . In the code calculations, different thermal reduction functions are permitted for Y and G ; however, no adjustment is made in $\bar{\epsilon}^P$.

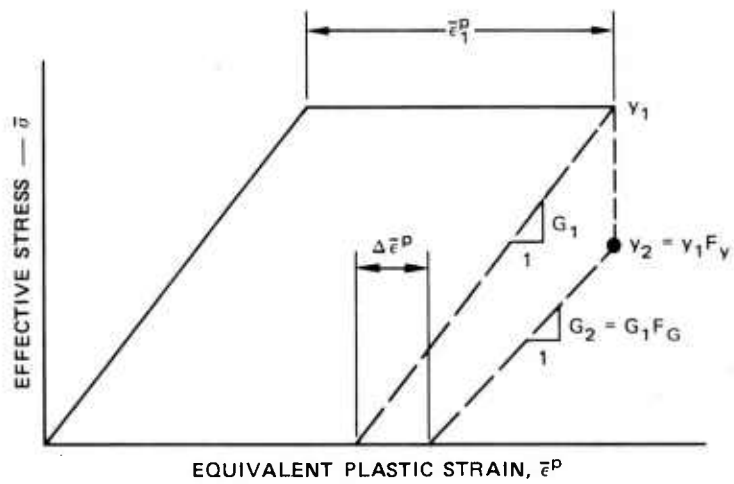
4.2 Constitutive Model Types and Switching Routine for Selecting Models

Constitutive or material models may take many forms besides the standard types presented above. Some of the available nonstandard models are introduced here, and the routine for calling them in the code is described. Procedures for inserting new models are described in Appendix H.

Our work in porous materials, fracture, composites, and explosives has led us to require the use of very general material models. PUFF models have been constructed to reflect these requirements. For example, a porous material may consolidate; therefore, calculations should be able to begin with the porous material model, but transfer to a solid model after consolidation. For fracture calculations it should be



(a) EQUAL THERMAL-SOFTENING FUNCTIONS



(b) UNEQUAL THERMAL-SOFTENING FUNCTIONS

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FIGURE 4.6 EFFECTS OF YIELD AND MODULUS THERMAL-SOFTENING FUNCTIONS ON PURE SHEAR STRESS-STRAIN RELATIONS

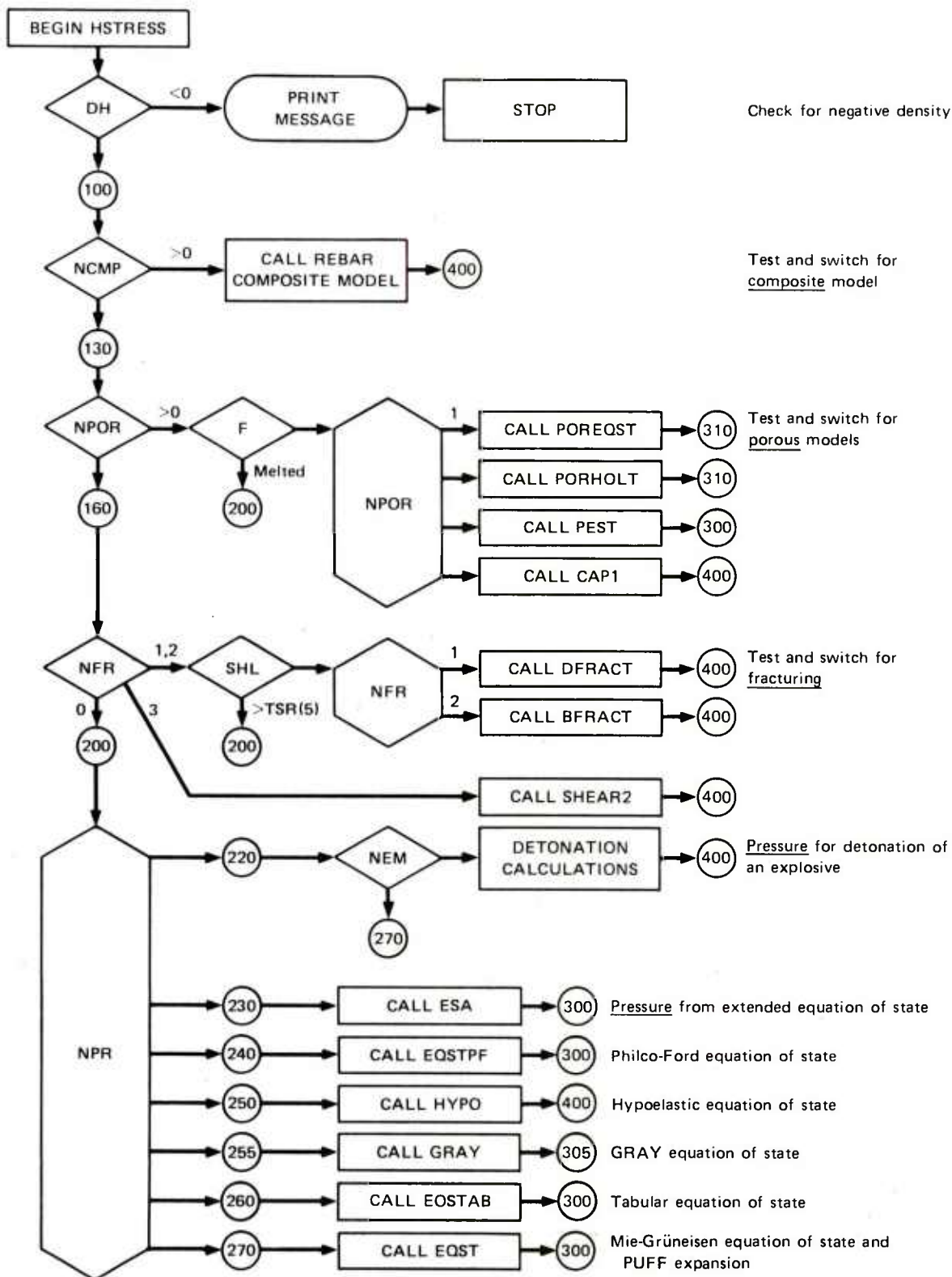
possible to treat the material with a continuum model up to incipient fracture and then transfer to a fracture model. Furthermore, the material state should determine which type of fracture model to call. Composites should be simulated either by a single model or by a combination of models representing the constituents. If pressure and deviator stresses are treated separately for the material, then any pressure model should be combinable with any deviator model. These general requirements have been followed in setting up the model types.

At present, five model types are accounted for in PUFF.

- Composite, for multiconstituent materials. Total stresses are computed by the model.
- Fracture. A continuum model is called until fracture begins. The use of a fracture model is triggered by a criterion preceding the CALL statement. Total stresses are computed.
- Porous. Either total stress or pressure are computed, depending on the model. At consolidation, transfer may occur to a continuum model.
- Deviator. Only deviator stresses are computed, so one of these models is used in conjunction with a pressure model.
- Pressure. Only pressure is computed. Explosives are treated under this heading.

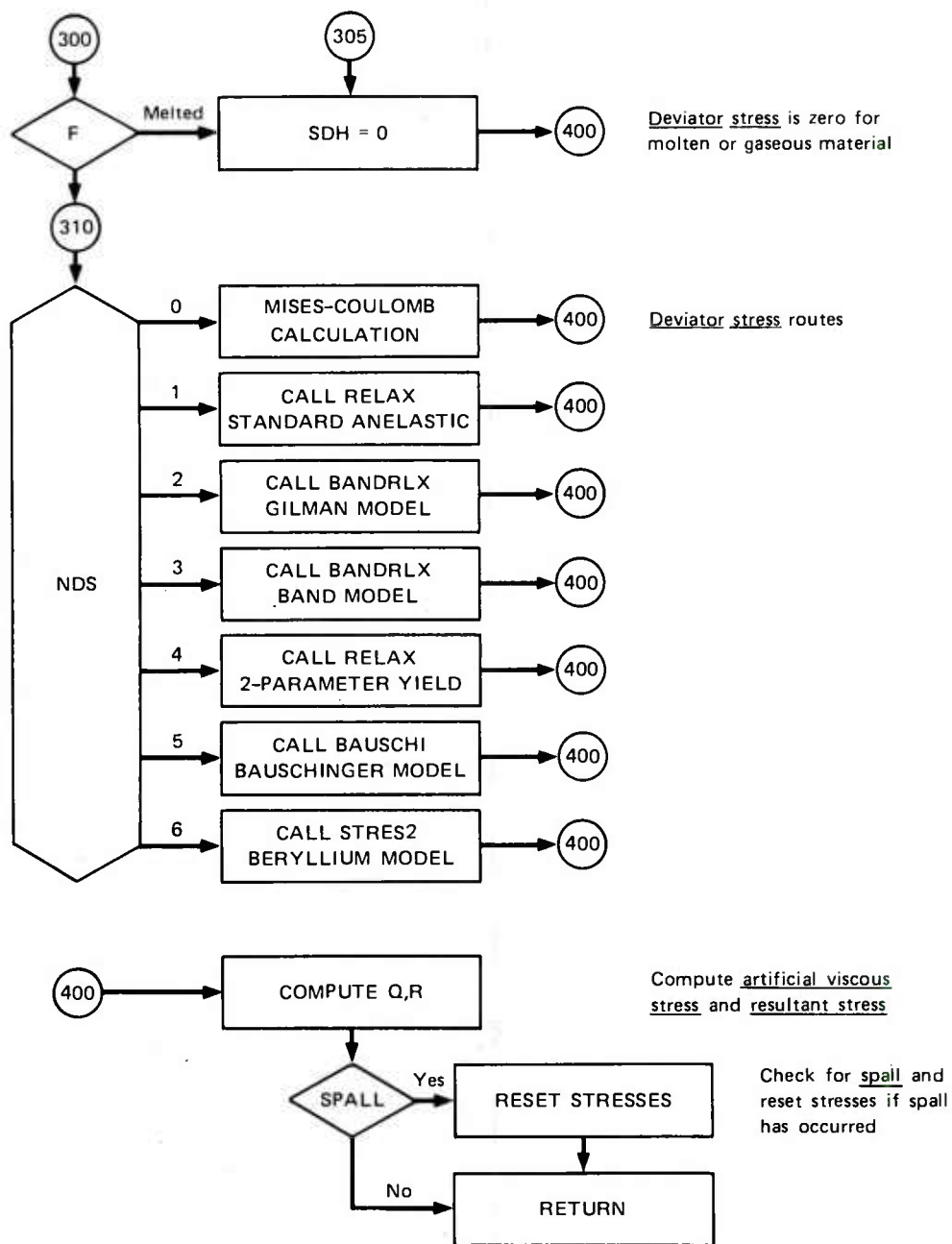
Occasionally still greater flexibility is required in modeling complex materials. For example, it may be necessary to use a particular deviator model first with a pressure model and then as part of a fracture model. Or it may be desirable to call a fracture model from a porous model. The capability of calling any model subroutine from any other routine is made possible by eliminating the COMMON variables from all models. All information enters each subroutine through its CALL statement. Hence special combinations of models can be obtained fairly readily with small changes in the program. Some guidance on making such changes is included in Appendix H.

The subroutine HSTRESS has been constructed to serve as a switch between the various subroutines computing pressure, deviator stress, and total stress. The flow chart in Figure 4.7 emphasizes these



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FIGURE 4.7 FLOW CHART OF HSTRESS, STRESS-SWITCHING ROUTINE



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FIGURE 4.7 FLOW CHART OF HSTRESS, STRESS-SWITCHING ROUTINE (Concluded)

stress-switching features. Material models that are currently available are listed in the figure and in Section 2. The list in Section 2 also shows where to find more information about each model.

4.3 Spall Calculations

A simple spall model is provided to permit material separation when the stress exceeds a critical level, T_J . The spall criterion is checked and separation calculations are made in HSTRESS following the normal stress calculations.

The spall criterion is based on $R = \sigma_1 + Q$ in the direction of propagation and on σ_2 and σ_3 in the other two directions. The stresses in the three directions are

- (1) $R = \sigma_1 + Q = \sigma'_1 + P + Q = SDH + PHL + Q$
- (2) $\sigma_2 = \sigma'_2 + P = -\frac{1}{2}\sigma'_1 + P$ for planar and spherical
 $= P + \sigma'_2 = PHL + SDT$ for cylindrical
- (3) $\sigma_3 = \sigma_2$ for planar and spherical
 $= P - \sigma'_1 - \sigma'_2 = PHL - SDH - SDT$ for cylindrical

The first step in the spall calculations is to compare the stresses in all three directions with the spall criterion T_J .

If spall has occurred in any direction, the stress in that direction is zeroed and elastic rebound (recompression) occurs in the other two directions. The final stress configuration is obtained by applying a compressive stress $\Delta\sigma_1^f$ equal in magnitude to the tensile stress $\Delta\sigma_1^f$ in the spall direction. Because the stress $\Delta\sigma_1^f$ is applied while allowing only strain (opening) in the spall direction, the pressure and deviator components are computed from the usual elastic relations for planar flow.

$$\Delta P^f = \frac{C}{C + \frac{4}{3}G} \Delta\sigma_1^f \quad (4.46)$$

$$\Delta\sigma_1^f = \frac{\frac{4}{3} G}{C + \frac{4}{3} G} \Delta\sigma_1^f \quad (4.47)$$

The change in deviator stress in the other two directions is $-\Delta\sigma_1^f/2$. From these relations, the final stresses in the three principal directions are computed.

$$\begin{aligned}\sigma_1 &\rightarrow 0 \\ \sigma_j &\rightarrow \sigma_j - \Delta P^f + \frac{1}{2}\Delta\sigma_1^f \\ \sigma_k &\rightarrow \sigma_k - \Delta P^f + \frac{1}{2}\Delta\sigma_1^f\end{aligned}$$

Similarly, the pressure becomes $P - \Delta P^f$ and the deviators are modified as follows

$$\begin{aligned}\sigma_1' &\rightarrow \sigma_1' - \Delta\sigma_1^f \\ \sigma_j' &\rightarrow \sigma_j' + \frac{1}{2}\Delta\sigma_1^f \\ \sigma_k' &\rightarrow \sigma_k' + \frac{1}{2}\Delta\sigma_1^f\end{aligned}$$

The spall model now in PUFF correctly treats spallation and continued separation. Since separation strain is not stored, reconsolidation is determined only by a return to a consolidated density. Spall is permitted in only one direction at a time.

5. INITIALIZATION: THE GENRAT GROUP

The GENRAT subroutine is called once at the beginning of each problem to read in all the data and initialize the COMMON storage. The GENRAT group includes DEPOS, EXTRA, HDATA, PRESCR, REDR, SCATTO. The sequence of major operations conducted by these subroutines is:

- Read general running instructions for the problem
- Read properties for each material
- Lay out a coordinate grid over all the materials
- Compute the absorption of radiated energy (for a radiation problem)
- Initialize the coordinate and cell arrays
- Print initial coordinate values.

This section describes the philosophy of the input, shows the derivation of equations, and contains guidance on the choice of input parameters.

The next four subsections describe the input deck used with PUFF. All the input information is organized to reflect the following guidelines:

- Each card or group of cards is labeled for ease of identification. For example, equation-of-state data begin with the identifier EQST; yield data begin with YIELD.
- Each input line is read and then printed immediately in the same format (echo printing) so that the first page of print-out looks like the input deck.
- The first column of each card is treated as an indicator to control the reading process, but it is not data.
- The minimum amount of data is used for each problem. For example, the required data for a material are contained on just two cards. On the first card are indicators that show whether more property cards are required because of special models used for the material.

GENRAT has the capability of performing several problems one after the other and for reading material properties or spectral data from a data bank on disk, tape, or cards. The input deck structure required for using these capabilities is described in the following subsection

and shown in sample decks in Appendix C. The initialization operations require the subroutines GENRAT, DEPOS, SCATTO, REDR, HDATA, and EXTRA. The following subsections describe four sets of data cards that may be used for each problem: general running data, materials data, cell layout, and radiation data. The first three sets are required for every problem, but the fourth is needed only for radiation problems.

5.1 Input of General Running Information

The first group of data identifies the computation and contains indicators controlling the length of the computation, the amount of printing, the number of materials and the type of computation.

The first or title card contains a brief title for the run. This line of information (plus the date) serves as a heading for each page of all major prints from the GENRAT, SCRIBE, and EDIT subroutines. The first character of this card serves as an indicator:

Blank - normal input continues.

- D - Deposition layout only; the next required input card is the NMTRLS card.
- T - The remainder of the general running data should be read from tape. On the tape these data records follow a title record containing the last 10 characters of the title card (See Appendix C).
- X - Same as "T", but in addition, data will be read in through the EXTRA routine following the NMTRLS card.

When the first character is blank, any number of comment cards may follow this first card if these cards contain a nonblank first column.

The second normal input (NTEDT) card contains some of the print controls (NTEDT and NJEDIT), the rezoning control (NREZON), and the geometry designator (NALPHA). NTEDT is the number of EDITS (print of condition of the coordinate array at a specified time) to be called, and NJEDIT is the number of lines containing coordinate locations (JEDITS) for which a stress history is to be printed. If NTEDT is nonzero, the next cards contain a list of the TEDITs or times at which the prints

will occur. If NJEDIT is nonzero, the following NJEDIT lines contain a list of indicators of the variables and J values of cells for which historical listings are needed: the format for these lines is described in Appendix C under Historical Prints. NREZON controls rezoning, i.e., resizing of cells and recomputation of associated coordinate and cell quantities at intervals during the computation. The type of rezoning depends on the sign of NREZON:

- A positive NREZON is the number of rezones desired, and two additional input cards containing lists of NTR and JREZON are required. NTR is the number of the TEDIT (hence the time at which each rezone is called); JREZON is the right-most coordinate in each rezone.
- If NREZON is negative, an input card containing DTMAX, TREZON, NARZ, and TARZ is required. DTMAX is the desired size of the time step DTNH and TREZON is the time interval between rezones. Rezoning is terminated if the number of rezones exceeds NARZ or the time exceeds TARZ. If NARZ and TARZ are zero, then rezoning continues at intervals of TREZON until DTNH exceeds DTMAX. If DTMAX is negative on the input card, it is interpreted as the number of cells desired in the material whose layer number is $L = -NREZON$. From this input value, DTMAX (in its usual significance) is computed in GENRAT.

The geometry designation NALPHA has the meaning:

- 0 or 1 Planar grid
- 2 Cylindrical layout with $X = 0$ at axis of cylinder
- 3 Spherical layout with $X = 0$ at center of sphere.

The subroutine REZONE can only increase the size of cells; therefore, cells should be laid out as small as desired initially. In REZONE it is presumed that the cell at JREZON (an input quantity for NREZON > 0 or a cell selected by REZONE for $NREZON < 0$) is of proper size, then all cells with smaller J values are resized to about the same thickness.

In a radiation deposition computation, small cells are needed at early times near the front surface to properly model the deposition, expansion, and spallation that occur in that region. After the deposition is complete, there is less need for the very small cells near the front. A reasonable approach to handling these requirements is to lay out the coordinates initially with a geometric size variation starting

with 10^{-4} to 10^{-5} cm cells at the front and possible increasing to 0.1 cm at the rear. Following deposition, the cells may be increased in size by rezoning. Because of the averaging operations that occur in REZONE, there is a loss of kinetic energy and some smoothing of the stress wave; therefore, rezoning should not be used excessively and cell sizes should not be more than doubled at each rezone.

For impact problems, a different procedure should be followed for rezoning and initial layout. To properly represent the stress history in the impact of a thin flyer on a target, 10 to 20 cells should be used in the flyer and similar sized cells should be used in the target at the impact point. Larger cells can be used deeper into the target. The appropriate time for rezoning is following the completion of the impact (twice the propagation time through the flyer). Usually one rezoning is sufficient to establish a suitable cell size for the balance of the computation.

Following the NTEDT card and the cards containing TEDITs, JEDITs, and rezoning controls is a card containing NEDIT and three termination criteria. NEDIT is the number of cycles between calls to EDIT. These EDIT calls are independent of those provided by the TEDIT array; hence this is a second procedure for requesting an EDIT printout. The parameters that are used to stop the running of the problem are JCYS, the number of major cycles or calls to the HYDRO subroutine that can be made before the program stops; CKS, the depth into the material beyond which the maximum stress should not move; and TS, the stop time. The calculation halts when any of these three is reached.

The last required data card in this group contains NMTRLs, the number of materials; MATFL, the number of the last layer of the flyer plate (neglect gaps in counting these layers); UZERO, the velocity of the flyer plate, and NSCRB, a set of 10 flags indicating whether plotting is called for from DEPOS. For problems other than impacts, MATFL acts as an indicator for the type of problem:

- Explosive detonation: set MATFL = 1, UZERO = 0. The problem is initiated by the energy insertion procedure in EXPLODE.

- Radiation deposition: set MATFL = 0. Then DEPOS is called to provide the energy deposition.
- Mirror impact: set MATFL = - 1 for a symmetric impact.
- Pressure boundary at J = 1: set MATFL = - 2 and provide a pressure history in FUNCTION SIGMAT (1, TIME) or read in P6(1) and T6(1) through the EXTRA routine following the normal data deck. The applied pressure has the form $P = P6(1) \exp(TIME/T6(1))$.
- Pressure boundary at J = JFIN: set MATFL = - 3 and provide a pressure history in SIGMAT(2, TIME) or read in P6(2) and T6(2) as for pressure at J = 1.

The plotting called for by the flags NSCRB(1) to NSCRB(3) occurs at the end of the layout and is controlled by DEPOS. The three flags pertain to plots of energy, pressure, and temperature, respectively, as functions of distance into the target. If one or more of these flags are nonzero, then x and y ranges for each plot are read in.

5.2 Input of Material Properties

Following the general running information are several sets of cards, one set for each material. The material properties information is grouped in the following categories:

- Material name, solid density, and a set of flags--NCMP, NFR, NPOR, NDS, NPR, NYAM, and NCON--which control the reading of additional data, plus NVAR, which controls the number of extra variables per cell available for the material (See Appendix C for NVAR). In the input listings in Appendix C, the first 6 indicators are labelled with the contracted titles CFP and DPY.
- Solid equation-of-state parameters: EQSTC, EQSTD, EQSTE, EQSTG, EQSTH, and EQSTS. EQSTC, EQSTD, and EQSTS are the parameters of the Hugoniot pressure function. The C,D,S form Eq. (4.6), the linear shock velocity relation or Murnaghan equation can be represented; EQSTS indicates which form is used. The three parameters have the following meanings:

	<u>C, D, S form</u>	<u>Murnaghan</u>	<u>Linear $U_s - U$</u>
EQSTC	C	a/b	C_L
EQSTD	D	b	S_L
EQSTS	S	1.0	2.0

The parameters EQSTG and EQSTH are the Grüneisen ratios Γ and H . EQSTE is the sublimation energy.

- Special data required for composite (NCMP), fracture (NFR), porous (NPOR), deviator stress (NDS), or pressure (NPR) models. Some of these are read in GENRAT, and some in the subroutine containing each model. See Nomenclature for meaning of each indicator.
- Optional material properties. TENS, spall strength values (Section 4.3); COSQ or VISC, artificial viscosity coefficients (Section 3.3); YIELD, yield strength and shear modulus (Section 4 and Appendix G); and EMELT, or MELT, GMELT, thermal strength reduction parameters (Appendix D). The number of these optional lines is NYAM.
- Radiation absorption data (NCON). NCON is the number of constituents of a material for which radiation absorption data are provided; hence mixtures, alloys, and composites are accounted for (Section 5.4 and Appendix A).

Of this imposing array, only the first and second lines are required. The flags that are read in on the first card indicate which, if any, of the other data items are supplied. The data under the control of NYAM are all given nominal values by GENRAT: these nominal values are used unless they are over-written by data from input. The spall strength within materials is initialized high to avoid spall, the spall strength between layers is low to permit separation, the yield strength is zero, quadratic and linear artificial viscosity coefficients are 4.0 and 0.15, respectively, and the thermal strength reduction function is set to degrade the strength gradually and permit melting at one-tenth the sublimation energy (EQSTE).

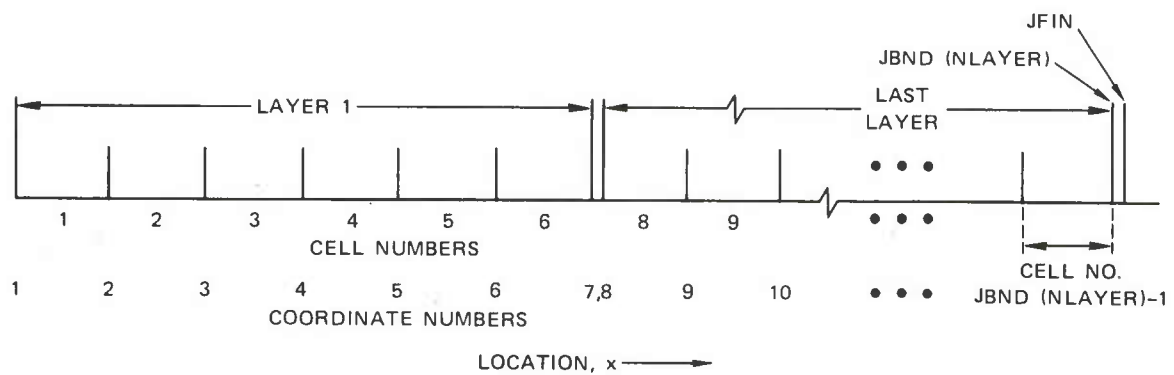
The material data in all the above categories may be provided either from a data bank or as part of the input deck. Details of the data deck setup for these two alternatives are given in Appendix C. If a data bank is used, it contains a series of card images corresponding exactly to those that would appear in a material properties deck. To indicate that a data bank is being used for the material data, one card is inserted containing a nonblank first column and the material name. Examples of such data decks are shown in Appendix C. The use of a data bank is especially convenient for multiple runs with an identical set of materials.

5.3 Layers and Cell Layout

The materials in the problem are laid out in a series of layers, and each layer is discretized into a number of finite difference cells. The total number of layers, including any empty layers or gaps, is given as NLayer. The array JMAT then provides the relationship between layers and materials. For example, for layer L, JMAT(L) is M, the material number. For an empty layer, JMAT(L) is zero. No finite difference cells or coordinates are used to represent gaps; adjacent layers of material are merely separated by the gap distance. Following the cell layout, NLayer is reduced by GENRAT to the number of layers containing material.

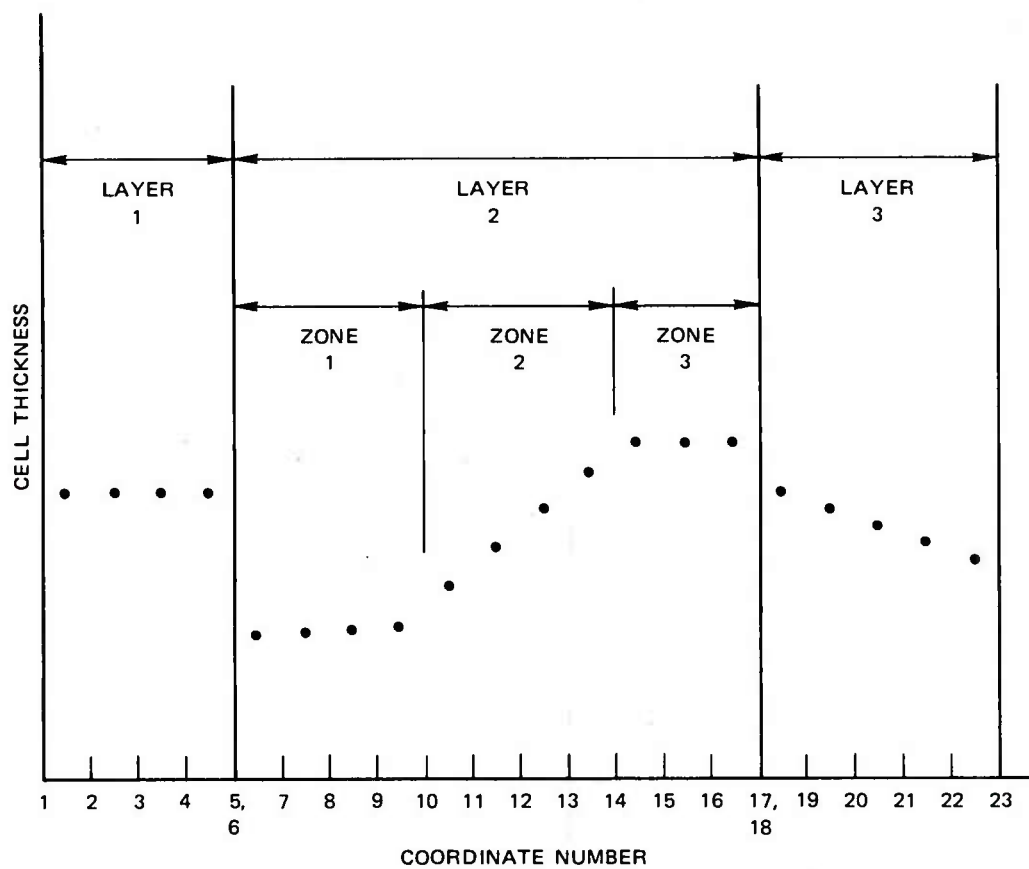
The materials in each layer are laid out in a Lagrangian grid (Lagrangian because the grid moves with the material), with variable spacing between the grid points. This variability allows for flexibility in planning the layout of the grid, for concentrating small cells near regions of interest, and for using large cells elsewhere. For best results in the computations, the cell sizes should be allowed to vary slowly. Each material is divided into one or more zones; within each zone the cell sizes are uniform or they vary in either an arithmetic or geometric progression. The numbering of cells and coordinates is shown in Figure 5.1. Each cell has the same number as the coordinate to the left. Energy (EHL), mass (ZHL), density (DHL), pressure (PHL), and stress (SHL) are the basic quantities associated with the cells or mid-cell points. The coordinate location (X) and velocity (U) refer to coordinate points. Figure 5.2 shows a possible variation of cell sizes (five different zones of varying sizes are possible for each layer; zones of geometric and arithmetic cell variations may be intermixed). The numbering system that is used for the grids is also shown in Figure 5.2; two coordinate numbers are assigned to interfaces between materials. The last coordinate point in each layer is called JBND(NL) where NL is the layer number. The last coordinate used is JFIN, which is one greater than the last JBND value; this definition of JFIN is useful for the operations in HYDRO.

The zoning input data are provided on a series of cards, one for each zone of each layer. The first card of the zoning set gives the



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FIGURE 5.1 COORDINATE LAYOUT FOR SRI PUFF



GA-6586-4A

FIGURE 5.2 COORDINATE LAYOUT SHOWING VARIABLE CELL SIZE CAPABILITY

number of layers (NLAYER) and the array (JMAT), which tells which material is in each layer of the layout. On the first card for each layer is the number of zones, NZONES; the number of cells in the first zone, NCELLS; the zone thickness, TH; the size of the first cell, DELX; and the size of the last cell of the zone in an arithmetic progression, DELFIN. For a geometric progression, DELFIN is interpreted as the RATIO between sizes of successive cells, and DELX is disregarded. For uniform cell sizes, DELX and DELFIN are omitted. For an arithmetic layout, either DELX or DELFIN is specified. A geometric layout is indicated by values for both DELX and DELFIN, although the actual value of DELX is disregarded. Examples of the cards appear in Appendix C.

The following analyses of the zoning are made to give the bases for the computer calculation and also to present formulas for the incremental thickness change between cells and for thicknesses of the first and last cells. It is often desirable to compute the increment and cell sizes before a propagation calculation to guarantee proper matching between cell sizes in different zones and ensure that the change in cell size is not too great within a zone. For the analysis of an arithmetic progression, the thickness of a zone T_h is first represented as a sum of the cell thickness ΔX_1

$$T_h = \sum \Delta X_1 = \Delta X_1 + (\Delta X_1 + \delta) + (\Delta X_1 + 2\delta) + [\Delta X_1 + (N_c - 1)\delta] \quad (5.1)$$

where $\Delta X_1 = \text{DELX}$ is the thickness of the first cell, δ is the incremental change in thickness from one cell to the next, and N_c is the number of cells in the zone. Using the formula for the sum of an arithmetic series Eq. (5.1) is changed to the following form:

$$T_h = N_c \Delta X_1 + \delta(N_c - 1)N_c/2 \quad (5.2)$$

Equation (5.2) can then be rearranged to obtain the equation for the incremental change in cell thickness, δ

$$\delta = 2 (T_h/N_c - \Delta X_1)/(N_c - 1) \quad (5.3)$$

According to Eq. (5.1), the expression for the thickness of the last cell, $\Delta X_f = \text{DELFIN}$, is the following

$$\Delta X_f = \Delta X_1 + (N_c - 1)\delta \quad (5.4)$$

Then Eq. (5.2) can be altered to give the form

$$T_h = N_c (\Delta X_1 + \Delta X_f) / 2 \quad (5.5)$$

Equation (5.5) can then be rearranged to provide expressions for evaluating the thickness of either the last cell in the zone, given the thickness of the first, or vice versa

$$\Delta X_f = 2T_h / N_c - \Delta X_1 \quad (5.6)$$

$$\Delta X_1 = 2T_h / N_c - \Delta X_f \quad (5.7)$$

When an arithmetic progression zoning is desired, either ΔX_1 or ΔX_f may be entered. For a uniform distribution of cell sizes, both ΔX_1 and ΔX_f should be left at zero.

For the geometric progression the input quantity DELFIN is interpreted as R_x , the ratio between successive cell sizes. The first cell has the thickness $\text{DELX} = \Delta X_1$, and the last cell thickness is

$$\Delta X_f = \Delta X_1 R_x^{(N_c - 1)} \quad (5.8)$$

The thickness of the zone is given by the usual sum of a geometric progression.

$$T_h = \Delta X_1 \frac{(1 - R_x^{N_c})}{1 - R_x} \quad (5.9)$$

The geometric cell layout is actually overspecified by the input. Therefore the input value of ΔX_1 is disregarded and ΔX_1 is computed from Eq. (5.9) and the given values of T_h , R_x , and N_c . The nonzero value of ΔX_1 in the input merely indicates a geometric layout. The geometric progression is particularly useful in radiation deposition problems

in which it may be necessary to vary cell thicknesses from 10^{-5} cm at the surface to 10^{-1} cm deep inside the material.

Correct sizing of the cells can be very important in getting useful results from a computation. No complete theory is available for optimizing cell sizes, but the following guide lines have been obtained:

- Small cells should be used at the surface of deposition in a radiation deposition problem. The cells should be small enough that no more than 1% of the energy is absorbed in the first cell. If vaporization occurs, several vaporizing cells should be provided.
- In an impact problem the cells on either side of the interface should be matched in such a way that the interface particle velocity computed on the first cycle is approximately equal to the final steady-state value. This sizing can be accomplished adequately if the cells are sized so that the times to traverse them are about equal; i.e., materials with low velocities should have smaller cells. The correct interface velocity need not be obtained on the first cycle, as the program will iterate to the correct value in a few cycles if the artificial viscosity coefficients have normal values. Large amounts of viscosity will slow the convergence of the iterations. It does not appear necessary to match cell sizes precisely across an interface, even the impact interface. A series of computations was made with an impact of C-7 epoxy ($\rho = 1.19$) and tungsten ($\rho = 19.3$). The "equal time" criterion above dictated that C-7 cells should be 5/8 as large as tungsten cells. Computations were made with C-7 cells 1/4, 5/8, 1.0, and 2.5 times as large as the tungsten cells. Even the most mismatched cases gave an initial overstress only 8% higher than the best matched case.
- For porous materials that are compacted during the computations, a large number of cells should be used to represent the material. This number is required to provide adequate definition of the material response during the compacting process. Generally, a half-consolidated cell is not a good average of an uncompacted cell and a solid cell.
- Rise times of stress waves are equal to several traverse times for the cells. Hence, the definition of the stress history can be used as a basis for defining acceptable cell sizes.
- Cell sizes can be varied gradually (less than 5% per cell) so that the cells are small and stress waves are sharply defined in regions of interest and large at other points in the flow. The material boundaries need be extended only far enough from the region of interest that no disturbing wave from the boundary reaches the region of interest during the problem time.

5.4 Thermal Energy Deposition

Thermal energy is deposited into the cells to simulate radiation from x-ray, electron beam, or laser sources. The energy is deposited into the cells at a constant rate during the shine time of the source. This section outlines the deposition options and required input. Appendix A contains more information about the energy deposition process. Initialization of deposition is handled in the subroutine DEPOS.

In SRI PUFF, several radiation sources may be used at once, each with its own spectrum and shine time. The sources may radiate at normal incidence onto the material layers (planar geometry is assumed) or at oblique angles. Each layer may have a different angle to treat radiation through several separate layers at different inclinations.

5.4.1 Deposition Types

Three deposition procedures are available for representing radiation from each source.

- Black body x-ray source. The radiation source is represented as a series of black bodies. The required data are energy reaching the surface (cal/cm^2), temperature of each black body (keV), and absorption coefficients for each material.
- Arbitrary x-ray spectrum. The radiation source is represented by a table of energies in $\text{calories}/\text{cm}^2$ versus $h\nu$ (photon energy or temperature, in keV) for each spectrum. Absorption coefficients for each material are required.
- A depth-dose profile in the form of a table of deposited energies ($\text{calories}/\text{g}$) versus depth (cm). This option permits use of x-ray deposition profiles from a code that treats scattering, fluorescence, and photoelectric effect or deposition from laser or electron beam sources. No absorption data are required with this option.

With the black body option, DEPOS constructs a spectrum consisting of 95 energy values at specific $h\nu$ (photon energy) points. Then the radiant energy that will be deposited in each finite difference cell is computed and stored in the SS array. The photoelectric absorption coefficients are used for the deposition calculation. Because absorption by Compton scattering and fluorescence is neglected, the DEPOS deposition calculation should not be relied on for black body temperatures greater than

a few keV. DEPOS treats the arbitrary spectrum the same as the black body spectrum for deposition calculations.

For the third deposition option, the depth-dose profile is used to calculate the radiant energy to be deposited in each finite difference cell. The energy for each cell is calculated (in SCATTO) by passing an interpolation function through sets of points in the profile and integrating the area under the function between the limits of the cell dimension.

5.4.2 Data Required

Three types of data are read into DEPOS for deposition calculations: photoelectric absorption data, spectra or black body temperatures, and depth-dose profiles. The absorption coefficient for x rays has the form shown in Figure 5.3. In a log-log plot there are sharp discontinuities at $h\nu$ values corresponding to the electron energy levels or edges. Between these edges the absorption function is usually fairly linear. The following function is used to fit the absorption data between edges:

$$\ln \sigma_a = A_0 + A_1 w + A_2 w^2 + A_3 w^3 \quad (5.10)$$

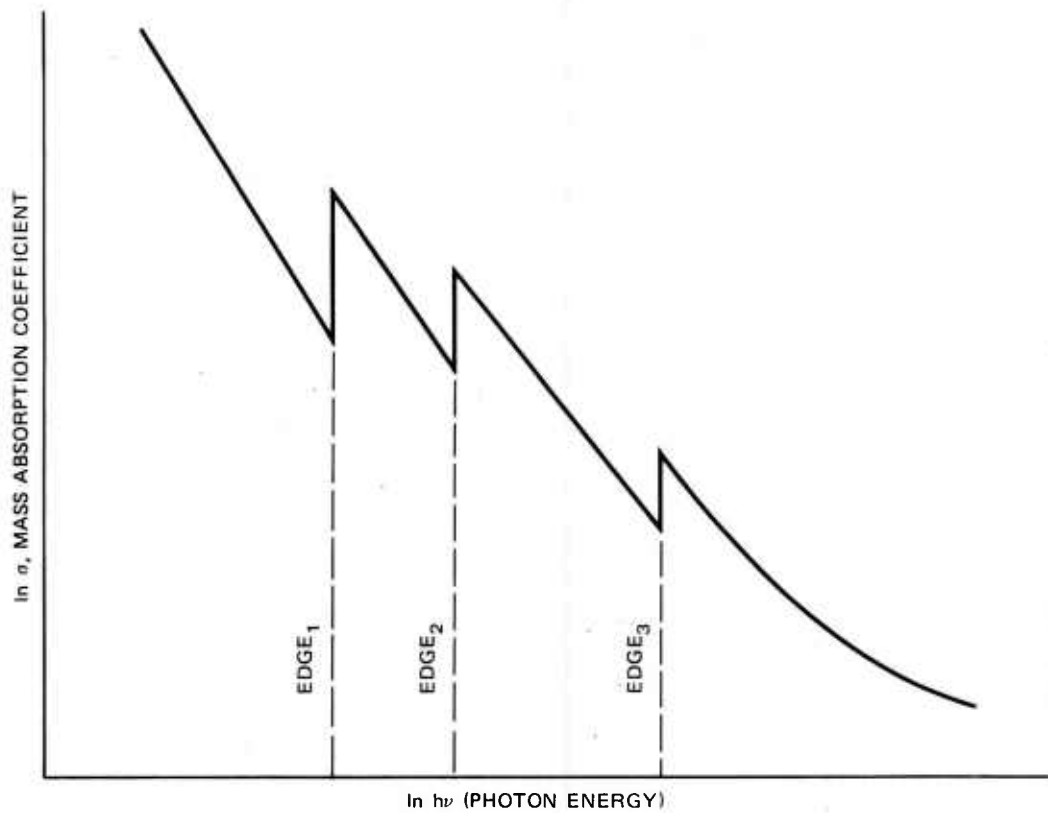
where σ_a = mass absorption coefficient (barns/atom)

$w = \ln(h\nu)$, with $h\nu$ in keV

$A_0 \dots A_3$ = coefficients of the fit.

The required data are the atomic weight, number of edges, and values of the edges and A 's for each interval between edges. Samples of the absorption data input are given in Appendix C.

The deposition data for any radiation problem include the number of spectra or sources (NSPEC), angles (ANGLE) between the shine direction and normal incidence, type of deposition, fluence (ECAL), and shine duration (SSTOP-START). For black body spectra, one line containing the temperature (TEMP) and fluence (ECAL) is required for each black body.



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FIGURE 5.3 TYPICAL VARIATION OF PHOTOELECTRIC MASS ABSORPTION COEFFICIENT WITH PHOTON ENERGY

For an arbitrary spectrum, the additional data are the number of $h\nu$ values (NHNU, not more than 109), the format for reading the table of data, and NHNU pairs of $h\nu$ (TBL) and energy (EI) values.

The data for a depth-dose profile are the number of pairs of points (NPOINT), the format for reading the profile data, and the pairs of depth (TBL) and dose (EI) values. Samples of all these radiation options are given in Appendix C.

5.4.3 Special Features

Many special features are often required for handling radiation problems: the available options are mentioned here.

Angles. If the layers are positioned at different inclinations, several values of ANGLE are required. The multiple angles require that positions 21 to 27 of the NSPEC line contain "ANGLES." Otherwise, all layers are assumed to have the inclination ANGLE(1).

Impulse. The impulse calculated by the McCloskey-Thompson formula is computed at each coordinate point. The impulse at point J is

$$I_J = 1.2 \sqrt{2 \int_1^J Z \left[E - E_m \left(1 + \ln \frac{E}{E_m} \right) \right] dZ} \quad (5.11)$$

where E = the deposited energy at a point

E_m = the melt energy

Z = the mass per unit area

I_J = impulse in dyn-sec/cm².

Multiple Sources. The present arrays are dimensioned for five sources. If more are required, SSTOP and START in the COMMON labeled /RAD/ should be redimensioned. The SS array may also require more storage. The SS array in labeled COMMON/SS/ should have a dimension at least as large as the number of sources times the number of coordinates.

Source Type Indicator. The source type indicator A1 is on the spectrum name line following the NSPEC line. A1 fills the 5 spaces

from columns 11 to 15 and contains "NARB", "NBB", or "NHNU" for depth-dose input, black body, or arbitrary spectrum, respectively.

Normalization of the Depth-Dose Profile. The depth-dose profile may be modified to permit changes in material density and in the fluence. For a porous material, the depth-dose profile is modified by changes in density only in proportion to the ratio of densities. To permit a density change, NARB is set less than zero on the line following the NSPEC line, and an additional line containing RHOOLD (the density associated with the depth-dose profile) is inserted. Then the profile is automatically adjusted for the new density.

The input depths in the depth-dose profile need not correspond to the x-values in the coordinate array because the depths will all be adjusted to match the first coordinate of each layer.

The depth-dose profile is usually provided normalized to a fluence of 1 cal/cm². Then the input variable ECAL is multiplied times the dose energies to obtain the energy in the problem. If the profile is not normalized, the fluence ECAL can be obtained by setting NARB to ± 1 . Then the profile is normalized before applying the factor ECAL.

5.5 Initialization of Arrays and Indicators

The input data are used to initialize the cell and coordinate arrays and various indicators. Included in this initialization are yield and work-hardening factors, sound speed, the H indicator array, the NEM, NET and LVAR arrays, and several scalar indicators.

The standard deviator model treats a yield strength that varies with work-hardening and Coulomb friction as follows:

$$Y = Y_1 + Y_D \Delta\rho + \beta P = YHL + YADD(M) \cdot \Delta\rho + EXMAT(M,1) \cdot P \quad (5.12)$$

where

Y_1 = the yield at the previous time (YHL)

Y_D = a work-hardening modulus (YADD)

β = a Coulomb friction factor (EXMAT)

P = the pressure.

The input value of the work-hardening modulus, YADD, has the strange formulation inherited from PUFF 66, where the increase in yield strength is

$$\Delta Y = \frac{\rho_2 - \rho_1}{\rho_0 (0.2 - \epsilon_{EL})} YADD \quad (5.13)$$

where

ρ_0 , ρ_1 and ρ_2 = the initial density and the densities before and after a time increment

ϵ_{EL} = strain to the Hugoniot elastic limit = $Y_0 / (2G)$

Y_0 = input yield strength = YOS in the code

G = shear modulus = MU(M).

To put this work-hardening relation into the form of Eq. (5.12), the modulus Y_D is defined as

$$Y_D = \frac{YADD(M)}{RHOS(M) * [0.2 - 0.5 * YOS/MU(M)]} \quad (5.14)$$

In GENRAT, YADD(M) is reset to Y_D .

The value of β is derived by examining the usual form of the Coulomb law (actually Coulomb-without-dilatation, a special form that permits no plastic volume change):

$$\tau_c = c + \sigma_N \tan \phi \quad (5.15)$$

where

τ_c = the shear stress at yield

c = the cohesion

σ_N = the normal stress on the yielding surface

ϕ = the angle of internal friction.

As shown in Section 4, this Coulomb law can be rewritten into the following form

$$Y = \frac{3c\sqrt{N_\phi}}{1 + N_\phi/2} + \frac{1.5 (N_\phi - 1)P}{1 + N_\phi/2} \quad (5.16)$$

where $N_\phi = \tan^2 (\pi/4 + \phi/2)$. Now Eq. (5.16) has the form of Eq. (5.12); we only need to determine the required constants from the input data. During input, YOS is read in with the value 2c and EXMAT(M,1) is read in as $\tan\phi$. Then Y0 and EXMAT are reset in GENRAT as follows:

$$Y0(M) = \frac{3c\sqrt{N_\phi}}{1 + N_\phi/2} \quad (5.17)$$

$$EXMAT(M,1) = \frac{1.5 (N_\phi - 1)}{1 + N_\phi/2} \quad (5.18)$$

The sound speed, CHL, is initialized in GENRAT according to the following rules:

$$\begin{aligned} CHL &= \sqrt{\frac{\text{bulk modulus} + 4/3 (\text{shear modulus})}{\text{density}}} && \text{for normal solids} \\ &= \text{detonation velocity for explosives} \\ &= EXMAT(M,3) \text{ for porous materials.} \end{aligned} \quad (5.19)$$

Here the value of EXMAT(M,3) is calculated in the porous subroutine--POREQST, PORHOLT, PEST or CAP1--during its initialization and passed back to GENRAT.

For explosives that are to undergo either a running detonation or constant volume explosion, GENRAT calls EXPLODE to insert the chemical energy in the EHL array and initialize NEM to the fraction detonated.

For some deviator models the NEM array is given special initial values as follows:

Band model: NEM = TSR(M,21)

Gilman model: NEM = TSR(M,19)

Bauschinger model: NEM = yield strength.

For the Band and Gilman models, the NEM values are the initial number of mobile dislocations.

The triple indicator array H is set so that H(J,1) shows the solid or porous state of the material, H(J,2) shows boundary conditions, and H(J,3) shows the path taken by the deviator stress. The boundary indicator has the meanings:

H(J,2) = N, normal coordinate inside a material

L, left interface of a layer

R, right interface of a layer

S, spalled interface or free surface

M, mirror or symmetric boundary

P, pressure history boundary

I, infinite boundary.

When extra cell variables in the COM array are required for a material model, NVAR is set by the user to the required number of variables. In GENRAT, NVAR is used to divide the COM array as described in Appendix C. The starting location in the COM array for variables of the Jth cell is LVAR(J): the LVAR array is initialized in GENRAT.

Several scalar indicators are also initialized in GENRAT. In non-radiation problems, the factor SDURM is set to 1.0 to eliminate calls to the deposition routines. For an impact problem, the particle velocity of the flyer materials is set to UZERO, the flyer velocity. For a symmetric impact, the velocity of the first boundary (the impact interface) is set to UZERO/2. The time-step variable DTNH is initialized to 10^{-12} second to begin the first cycle of wave propagation calculations.

5.6 Initial Status Printouts

The initial configuration for the entire grid is printed out in either a deposition edit from DEPOS or velocity edit from GENRAT. Included in the deposition edit are the values of J, coordinate of each cell; DX,

the cell thickness; X, the coordinate in inches and centimeters; four variables indicating the energy in the cells; the cell temperature in degrees centigrade; pressure from an instantaneous deposition; impulse from the McCloskey-Thompson integral; the material name, MATL; and the condition variables, H. The energy quantities are the deposited energy in erg/g and cal/g, the cumulative amount of energy absorbed in cal/cm², and the fraction transmitted through each coordinate plane.

The velocity edit lists J, DX, X, U (particle velocity), yield strength, sound speed, density, spall strength, mass, internal energy and the H indicators. A sample edit listing is given in Figure 5.4.

DATE = 78/08/17. IDENT 4409-1												DUCTILE FRACTURE IN HOT 1145 AL UNDER IMPACT												SHOCKEY																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											
J	DX	X(J)	U(J)	YHL(J)	CHL(J)	DHL(J)	T(J)	7HL(J)	EH(J)	MATERIAL	COND	J	DX	X(J)	U(J)	YHL(J)	CHL(J)	DHL(J)	T(J)	7HL(J)	EH(J)	MATERIAL	COND	J	DX	X(J)	U(J)	YHL(J)	CHL(J)	DHL(J)	T(J)	7HL(J)	EH(J)	MATERIAL	COND	J																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
	CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC	GM/CM3	DYN/CM2	GM/CM2	ERG/GM					CM	CM	CM/SEC	DYN/CM2	CM/SEC

FIGURE 5.4 INITIAL STATUS OUTPUT FROM GENRAT FOR AN IMPACT OF A 1145 ALUMINUM PLATE ONTO A HOT ALUMINUM PLATE AT 1.46 x 10⁴ cm/sec

6. PRINTED OUTPUT: GENRAT, EDIT, AND SCRIBE

Several types of printed output are provided during and at the conclusion of a calculation. During the reading of the input, the input lines are printed by GENRAT with some additional comments. Some material property subroutines read their own input and provide printout. After the input is read, a layout listing is given by GENRAT (or DEPOS for a deposition problem). During the calculation several listings of the layout with current cell variables are made by EDIT (on a call from SRI PUFF). A final EDIT listing is made at the end of the calculation. The SCRIBE is called by SRI PUFF to print historical listings of all requested variables. Besides these standard listings, there are error messages, periodic messages, and special listings by some material models. Samples of these listings are given in this section.

During the reading of input by GENRAT and other routines, an echo listing is made of the input, as shown in Figure 6.1. In addition to this echo printing, the GENRAT listing includes prints to the right of the input lines and some interpolated prints between input lines. The prints to the right show the contents of the first column on the input line (IND), the file containing the input (IN), and the units of the data if read in GENRAT. If the input is read by another subroutine, that subroutine's name is listed (e.g., DEPOS and EXTRA in Figure 6.1).

Inserted lines in the input listing include the spaces separating data groups and the notation of an end-of-file found by EXTRA. EQST provides messages when the McCloskey-Thompson logarithmic variation of sublimation energy is used: some messages are explanatory, others indicate errors that will cause a program stop. When either the Murnaghan or linear shock velocity Hugoniot forms are used, EQST provides a message. FMELT provides a message if the FMELT function does not monotonically decrease with increasing internal energy. EXPLODE lists

```

DATE = 78/03/17.
IDENT = NEUTRON GEN/CONFIGURATION W/ZRCLY-2 CLADDING
NTEOT = 1 NJEDIT = -0. 1 NREZON = 0
TEDIT = 1.000E-09-0. -0. -0. -0.
JEOTI = S1.1.03.1.06.1.09.1.2.1.4.1.6.1.8.2.5.3.5.4.5
NEOIT = 5 JCVCs = 0 CKS = 1.000E+01 TS = 6.000E-06 IND= 1 IN= 5 SEC
NMTRLs = 4 MATFL = 0 UZERO = 0. ***** IND= 1 IN= 5 CM, SEC
NSCRB INDICATORS - RAO. PLOTS 1-E, 2-T, 3-P, 4- , SCRIIBE HISTORIES 1-6S, 2-1S, 3-OS, 1, 4-R, V, 5-U, 1, 6-NEM, NET
1-6S, 2-1S, 3-OS, 1, 4-R, V, 5-U, 1, 6-NEM, NET

U-3PCTMO
RHOS = 1.786E+01 CFP = 000 DPy = 004
EGST = 1.202E+12 1.459E+12 2.059E+10 2.030E+00 2.500E-01 5.840E+12-0. -0 IND= 1 IN= 5
MELT = 2.050E+09 1.271E+09 1.160E-01 5.000E-02 0. -0. -0. IND= 1 IN= 5 SEC
YIELD = 9.100E+08 6.314E+14-0. -0. -0. -0. -0. IND= 1 IN= 5
TENS = -8.000E+09-1.000E+11 0. 0. 0. 0. 0. IND= 1 IN= 5 CM, SEC
VISC = 4.000E+00 5.000E-02 5.000E-02 0. 0. 0. 0. IND= 1 IN= 5 CM/SEC

NA-600C
RHOS = 8.080E-01 CFP = 000 DPy = 001
EGST = 3.200E+10 0. 1.000E+11 1.000E+00 2.500E-01-0. -0. -0 IND= 1 IN= 5 G/CM3
TENS = -1.000E+11-1.000E+11 0. 0. 0. 0. -0. IND= 1 IN= 5 DYN/CM2, ERG/G, , DYN/CM2, ERG/G

ZIRCALOY-2
RHOS = 6.550E+00 CFP = 000 DPy = 004
EGST = 9.031E+11 0. 6.714E+10 7.700E-01 2.500E-01 0. -0. -0 IND= 1 IN= 5 G/CM3
EMELT = 6.615E+09 2.381E+07-7.200E-02 2.400E-01-6.000E-02-0. -0. -0 IND= 1 IN= 5 DYN/CM2, ERG/G, , OYN/CM2, ERG/G
VISC = 4.000E+00 5.000E-02 5.000E-02 0. 0. 0. 0. -0. IND= 1 IN= 5 ERG/G,
TENS = -1.000E+11-1.000E+11 0. 0. 0. 0. 0. -0. IND= 1 IN= 5 DYN/CM2,
YIELD = 3.000E+09 3.472E+11-0. -0. -0. -0. 0. IND= 1 IN= 5 DYN/CM2, DYN/CM2,

NAK-100C
RHOS = 8.470E-01 CFP = 000 DPy = 001
EGST = 5.300E+10 0. 1.000E+11 1.000E+00 2.500E-01-0. -0. -0 IND= 1 IN= 5 G/CM3
TENS = -1.000E+11-1.000E+11-1.000E+11 0. 0. 0. -0. IND= 1 IN= 5 DYN/CM2, ERG/G, , OYN/CM2, ERG/G

NLAYERS = 4 JMAT = 1 2 3 4 -0 -0 -0 -0 -0 -0 IND= 1 IN= 5 CM, CM,
NZONES= 1 29 CELLS IN 5.350E-01 CM OX = 6.000E-03 RATIO = 9.346E-01 IND= 1 IN= 5 CM, CM,
NZONES= 1 3 CELLS IN 1.270E-02 CM -0. -0. -0. -0. IND= 1 IN= 5 CM, CM,
NZONES= 1 3 CELLS IN 2.540E-02 CM -0. -0. -0. -0. IND= 1 IN= 5 CM, CM,
NZONES= 1 12 CELLS IN 5.000E-02 CM -0. -0. -0. -0. IND= 1 IN= 5 CM, CM,
NSPEC = 1 ANGLE = 0. -0. -0. -0. -0. -0. -0. -0. IND= 1 IN= 5 X -DEPOS- ANGLE FROM NORMAL (DEG)
PROTON NARB = 0 ECAL = .590E+00 START = 0. SSTOP = .200E-06 IND= 1 IN= 5 -DEPOS- , , CAL/CM2, SEC, SEC
IDENT = U TH = NP = 4 (1P8E10.3) IND= 1 IN= 5 -DEPOS- CM, ERG/G
0. 1.000E+00 2.000E-01 1.000E+00 4.000E-01 1.000E+00 5.350E-01 1.000E+00 IND= 1 IN= 5 -DEPOS- CM, ERG/G
IDENT = NA TH = NP 3 (1P8E10.3) IND= 1 IN= 5 -DEPOS- CM, ERG/G
0. 4.000E-01 6.350E-03 4.000E-01 1.270E-02 4.000E-01 IND= 1 IN= 5 -DEPOS- CM, ERG/G
IDENT = ZRCLY-2 TH = NP 3 (1P8E10.3) IND= 1 IN= 5 -DEPOS- CM, ERG/G
0. 4.000E-01 1.270E-02 4.000E-01 2.540E-02 4.000E-01 IND= 1 IN= 5 -DEPOS- CM, ERG/G
IDENT = NAK TH = NP 3 (1P8E10.3) IND= 1 IN= 5 -DEPOS- CM, ERG/G
0. 4.000E-01 2.000E-02 4.000E-01 5.000E-02 4.000E-01 IND= 1 IN= 5 -DEPOS- CM, ERG/G
H = 1 2 M H = 52 2
$NLIST RHOS(1)=1.845E+01, EQSTN(1)=1.55867E0, EHL(1)=30*1.065E+09$
EOF ENCOUNTERED BY EXTRA
INPUT FROM -FXTRA- ROUTINE

```

FIGURE 6.1 SAMPLE GENRAT LISTING OF INPUT DATA FOR A RADIATION PROBLEM

the type of detonation that will occur, and the C-J parameters if a running detonation is indicated.

For all problems, a listing of the initial cell layout and principal cell quantities is given. A GENRAT layout listing is shown in Figure 6.2. A sample radiation deposition layout from DEPOS is in Figure 6.3. In the DEPOS listing, a $J = 0$ line is provided for each layer to permit printing quantities pertaining to the first coordinate point in addition to quantities for the first cell.

Following the layout listing is the printing from PRESCR of the variables for which a historical listing is requested. A sample is given in Figure 6.4. This list is provided before the propagation calculations so that a verification of the correct histories may be made without a complete run.

During the calculation there are usually many calls to EDIT to produce listings such as that in Figure 6.5. The last two columns contain a variety of variables depending on the material models used and the material state. For the explosive (COMPB) in the first layer, the penultimate column provides FBURN, the fraction of explosive detonated. For the HF-1 in the second layer, the columns initially contain the yield strength (Y) and deviator stress (SD), but after shear banding begins at a cell, they contain $\text{TAU} = \epsilon \text{NL}^3$ and N, where N is the number of shear bands per cubic centimeter and L is the radius of the bands.

A sample of the historical listings provided by SCRIBE at the end of a calculation is in Figure 6.6. The variables in the first columns are provided automatically: cycle number N, problem time TIME, time step DTNH, calculational time for the cycle DELTIM, and the cell number controlling the time step JTS. Interface stresses are labeled S-INT(n) where n is the interface number and $n = 0$ means the front surface. For all other quantities, a standard label for the quantity is followed by the J value in parentheses.

Figure 6.7 contains other listings and messages found in PUFF output. Every 25 cycles a message like the periodic print in the figure is given. Preceding the final EDIT listing at the termination of the run, there is

DATE = 78/03/09. IDENT PROJECTILE INPUT ON CONCRETE AT 22.34M/SEC - TEST REBAR

J	DX CM	X(J) CM	U(J) CM/SEC	YHL(J) DYN/CM2	CHL(J) CM/SEC	DHL(J) GM/CM3	T(J) DYN/CM2	ZHL(J) GM/CM2	EHL(J) ERG/GM	MATERIAL	COND	J
1	7.257E-01	0.	2.234E+03	1.222E+10	5.843E+05	7.850E+00	-1.000E+11	5.697E+00	0.	IMPACTOR	S S B	1
2	7.257E-01	7.257E-01	2.234E+03	1.222E+10	5.843E+05	7.850E+00	-1.000E+11	5.697E+00	0.	IMPACTOR	S N B	2
3	7.257E-01	1.451E+00	2.234E+03	1.222E+10	5.843E+05	7.850E+00	-1.000E+11	5.697E+00	0.	IMPACTOR	S N B	3
4	7.257E-01	2.177E+00	2.234E+03	1.222E+10	5.843E+05	7.850E+00	-1.000E+11	5.697E+00	0.	IMPACTOR	S N B	4
5	7.257E-01	2.903E+00	2.234E+03	1.222E+10	5.843E+05	7.850E+00	-1.000E+11	5.697E+00	0.	IMPACTOR	S N B	5
6	7.257E-01	3.629E+00	2.234E+03	1.222E+10	5.843E+05	7.850E+00	-1.000E+11	5.697E+00	0.	IMPACTOR	S N B	6
7	7.257E-01	4.354E+00	2.234E+03	1.222E+10	5.843E+05	7.850E+00	-1.000E+11	5.697E+00	0.	IMPACTOR	S N B	7
8	7.257E-01	5.080E+00	2.234E+03	1.222E+10	5.843E+05	7.850E+00	-1.000E+11	5.697E+00	0.	IMPACTOR	S N B	8
9	7.257E-01	5.806E+00	2.234E+03	1.222E+10	5.843E+05	7.850E+00	-1.000E+11	5.697E+00	0.	IMPACTOR	S N B	9
10	7.257E-01	6.531E+00	2.234E+03	1.222E+10	5.843E+05	7.850E+00	-1.000E+11	5.697E+00	0.	IMPACTOR	S N B	10
11	7.257E-01	7.257E+00	2.234E+03	1.222E+10	5.843E+05	7.850E+00	-1.000E+11	5.697E+00	0.	IMPACTOR	S N B	11
12	7.257E-01	7.983E+00	2.234E+03	1.222E+10	5.843E+05	7.850E+00	-1.000E+11	5.697E+00	0.	IMPACTOR	S N B	12
13	7.257E-01	8.709E+00	2.234E+03	1.222E+10	5.843E+05	7.850E+00	-1.000E+11	5.697E+00	0.	IMPACTOR	S N B	13
14	7.257E-01	9.434E+00	2.234E+03	1.222E+10	5.843E+05	7.850E+00	-1.000E+11	5.697E+00	0.	IMPACTOR	S N B	14
15	0.	1.016E+01	2.234E+03	1.222E+10	5.843E+05	7.850E+00	-1.000E+11	5.697E+00	0.	IMPACTOR	S L B	15
16	5.080E-01	1.016E+01	0.	0.	4.995E+05	2.220E+00	-1.000E+11	1.128E+00	0.	CONCRETE	P R B	16
17	0.	1.067E+01	0.	0.	4.995E+05	2.220E+00	-1.000E+11	1.128E+00	0.	CONCRETE	P L B	17
18	5.080E-01	1.067E+01	0.	0.	5.458E+05	2.501E+00	-1.000E+11	1.271E+00	0.	REBAR	S R B	18
19	0.	1.118E+01	0.	0.	5.458E+05	2.501E+00	-1.000E+11	1.271E+00	0.	REBAR	S L B	19
20	5.080E-01	1.118E+01	0.	0.	4.995E+05	2.220E+00	-1.000E+11	1.128E+00	0.	CONCRETE	P R B	20
21	5.080E-01	1.168E+01	0.	0.	4.995E+05	2.220E+00	-1.000E+11	1.128E+00	0.	CONCRETE	P N B	21
22	5.080E-01	1.219E+01	0.	0.	4.995E+05	2.220E+00	-1.000E+11	1.128E+00	0.	CONCRETE	P N B	22
23	5.080E-01	1.270E+01	0.	0.	4.995E+05	2.220E+00	-1.000E+11	1.128E+00	0.	CONCRETE	P N B	23
24	5.080E-01	1.321E+01	0.	0.	4.995E+05	2.220E+00	-1.000E+11	1.128E+00	0.	CONCRETE	P N B	24
25	5.080E-01	1.372E+01	0.	0.	4.995E+05	2.220E+00	-1.000E+11	1.128E+00	0.	CONCRETE	P N B	25
26	0.	1.422E+01	0.	0.	4.995E+05	2.220E+00	-1.000E+11	1.128E+00	0.	CONCRETE	P L B	26
27	5.080E-01	1.422E+01	0.	0.	5.458E+05	2.501E+00	-1.000E+11	1.271E+00	0.	REBAR	S R B	27
28	0.	1.473E+01	0.	0.	5.458E+05	2.501E+00	-1.000E+11	1.271E+00	0.	REBAR	S L B	28
29	5.080E-01	1.473E+01	0.	0.	4.995E+05	2.220E+00	-1.000E+11	1.128E+00	0.	CONCRETE	P R B	29
30	0.	1.524E+01	0.	0.	4.995E+05	2.220E+00	-1.000E+11	1.128E+00	0.	CONCRETE	P L B	30

TIME TO COMPLETE GENRAT IS .530 SECONDS.

FIGURE 6.2 SAMPLE GENRAT LISTING OF THE CELL LAYOUT FOR AN IMPACT OF A STEEL PROJECTILE ONTO REINFORCED CONCRETE

DATE = 78/03/17. IDENT = NEUTRON GEN/CONF/IGURATION W/7HCLY-2 CLADDING

J	INCH	X	CM	DEPOS	OEPOS	PCT TR.	TEMP.	PRESS.	IMPULSE	MATERIAL	CUMUL.	J	OX	CM	ANSORRED
				UM/CM	CM/GM		DEC. C	KBAR	ATAPS						CAL/CM2
0	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	1000.000	0.	8.955E-01	0.	U-3PCTMU	S N M	1	4.072E-02		4.291
1	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	924.587	0.	8.797E-01	0.	U-3PCTMU	S N M	2	3.805E-02		4.301
2	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	858.109	0.	8.797E-01	0.	U-3PCTMU	S N M	3	3.538E-02		15.951
3	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	792.631	0.	8.797E-01	0.	U-3PCTMU	S N M	4	3.270E-02		15.951
4	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	726.231	0.	8.797E-01	0.	U-3PCTMU	S N M	5	3.002E-02		16.824
5	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	660.134	0.	8.797E-01	0.	U-3PCTMU	S N M	6	2.733E-02		21.884
6	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	615.359	0.	8.797E-01	0.	U-3PCTMU	S N M	7	2.465E-02		27.416
7	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	565.102	0.	8.797E-01	0.	U-3PCTMU	S N M	8	2.197E-02		29.913
8	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	518.131	0.	8.797E-01	0.	U-3PCTMU	S N M	9	1.929E-02		32.247
9	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	474.233	0.	8.797E-01	0.	U-3PCTMU	S N M	10	1.661E-02		34.429
10	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	433.205	0.	8.797E-01	0.	U-3PCTMU	S N M	11	1.393E-02		36.466
11	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	394.860	0.	8.797E-01	0.	U-3PCTMU	S N M	12	1.125E-02		38.374
12	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	355.023	0.	8.797E-01	0.	U-3PCTMU	S N M	13	8.570E-03		40.155
13	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	325.530	0.	8.797E-01	0.	U-3PCTMU	S N M	14	5.902E-03		41.979
14	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	295.258	0.	8.797E-01	0.	U-3PCTMU	S N M	15	3.234E-03		43.820
15	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	265.012	0.	8.797E-01	0.	U-3PCTMU	S N M	16	5.610E-03		45.682
16	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	234.782	0.	8.797E-01	0.	U-3PCTMU	S N M	17	3.042E-03		47.557
17	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	204.576	0.	8.797E-01	0.	U-3PCTMU	S N M	18	4.429E-03		49.451
18	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	174.393	0.	8.797E-01	0.	U-3PCTMU	S N M	19	1.868E-02		51.372
19	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	144.243	0.	8.797E-01	0.	U-3PCTMU	S N M	20	1.600E-02		53.302
20	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	114.112	0.	8.797E-01	0.	U-3PCTMU	S N M	21	1.332E-02		55.241
21	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	83.962	0.	8.797E-01	0.	U-3PCTMU	S N M	22	1.064E-02		57.182
22	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	53.812	0.	8.797E-01	0.	U-3PCTMU	S N M	23	7.970E-03		59.132
23	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	23.662	0.	8.797E-01	0.	U-3PCTMU	S N M	24	5.302E-03		61.082
24	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	7.512	0.	8.797E-01	0.	U-3PCTMU	S N M	25	2.634E-03		63.032
25	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	26	0.000E-03		64.982
26	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	27	0.000E-03		66.932
27	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	28	0.000E-03		68.882
28	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	29	0.000E-03		70.832
29	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	30	0.000E-03		72.782
30	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	31	0.000E-03		74.732
31	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	32	0.000E-03		76.682
32	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	33	0.000E-03		78.632
33	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	34	0.000E-03		80.582
34	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	35	0.000E-03		82.532
35	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	36	0.000E-03		84.482
36	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	37	0.000E-03		86.432
37	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	38	0.000E-03		88.382
38	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	39	0.000E-03		90.332
39	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	40	0.000E-03		92.282
40	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	41	0.000E-03		94.232
41	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	42	0.000E-03		96.182
42	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	43	0.000E-03		98.132
43	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	44	0.000E-03		100.082
44	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	45	0.000E-03		102.032
45	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	46	0.000E-03		103.982
46	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	47	0.000E-03		105.932
47	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	48	0.000E-03		107.882
48	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	49	0.000E-03		109.832
49	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	50	0.000E-03		111.782
50	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	51	0.000E-03		113.732
51	0.00000	0.00000	0.00000	2.47E+07	5.900E-01	0.000	0.	8.797E-01	0.	U-3PCTMU	S N M	52	0.000E-03		115.682

FIGURE 6.3 SAMPLE DEPOS LISTING OF THE CELL LAYOUT FOR A RADIATION PROBLEM

DATE = 77/02/17. IDENT FR 4 FRAGMIG HNO DF HF-1 TO SIMULATE CROWES TESTS 1 AND 2.

TIME EDIT NO. 30 AT N = 300. TIME = 5.03722E-05 SECS, JSTAR = 22. CALC TIME IS 48.348 SECS. DTNH = 1.189E-07 SECS

CELL	J	X	CM	CM/SEC	U	RHL	DYN/CM2	PHL	DYN/CM2	PHL	SHL	SHL	EHL	ERGS	DHL	CM/SEC	CHL	COND	FRURN	NET
1	0.000000																			
2	.885987																			
3	1.741600																			
4	2.558029																			
5	3.340054																			
6	4.141754																			
7	4.981754																			
8	5.792237																			
9	6.603248																			
10	7.433143																			
11	8.282992																			
12	8.282992																			
13	8.388019																			
14	8.497585																			
15	8.611523																			
16	8.729654																			
17	8.851607																			
18	8.977780																			
19	9.107458																			
20	9.245722																			
21	9.382373																			
22	9.522458																			

FIGURE 6.5 SAMPLE EDIT LISTING OF CELL VARIABLES AT ONE TIME DURING THE CALCULATION

DATE = 77/02/17. IDENT FR 4 PHAGMITG RND OF HF-1 TO SIMULATE CROWES TESTS 1 AND 2.

SCRIBE NO.

N	TIME	1 USUAL UNITS	ARE DYN, CM, SEC, GRAM, EXCEPT TIME IN MICROSEC, DTNH IN NANOSEC	JTS S-INT(11)	S1(12)	S1(13)	S1(14)	S1(15)	S1(16)	S1(17)
1.	.010	9.585	.674	7.076E+10	-9.314E-03	0.	0.	0.	0.	0.
2.	.021	11.502	.030	7.082E+10	1.411E+08	-9.314E-03	0.	0.	0.	0.
3.	.035	13.802	.034	7.100E+10	5.116E+08	9.008E+05	0.	0.	0.	0.
4.	.051	16.563	.037	7.135E+10	1.251E+09	5.225E+05	-9.314E-03	0.	0.	0.
5.	.071	19.875	.038	7.196E+10	2.519E+09	1.921E+07	5.786E+04	1.383E+01	0.	0.
6.	.095	23.850	.041	7.296E+10	4.613E+09	5.725E+07	3.001E+05	2.000E+02	-7.337E-03	0.
7.	.124	28.620	.043	7.522E+10	7.899E+09	1.515E+08	1.239E+06	1.688E+03	7.356E-01	0.
8.	.158	34.344	.043	7.687E+10	1.288E+10	3.678E+08	4.463E+06	2.200E+01	1.200E+01	0.
9.	.199	41.213	.049	8.024E+10	2.004E+10	8.455E+08	1.479E+07	1.372E+05	2.275E+02	-9.314E-03
10.	.249	49.456	.050	8.366E+10	2.753E+10	1.855E+09	4.628E+07	6.486E+05	2.211E+03	2.666E+00
11.	.308	59.347	.191	8.794E+10	3.703E+10	3.854E+09	1.387E+08	2.740E+06	1.629E+04	4.612E+01
12.	.379	71.216	.056	9.359E+10	4.968E+10	7.615E+09	3.979E+08	1.118E+07	1.621E+05	5.237E+02
13.	.465	85.460	.056	1.009E+11	6.630E+10	1.476E+10	1.092E+09	4.322E+07	1.015E+06	7.169E+03
14.	.567	102.551	.062	1.100E+11	8.659E+10	2.351E+10	2.866E+09	1.611E+08	5.508E+06	6.947E+04
15.	.690	123.062	.063	1.197E+11	1.092E+11	3.542E+10	6.970E+09	5.771E+08	2.765E+07	7.720E+05
16.	.838	147.674	.069	1.276E+11	1.293E+11	5.400E+10	1.551E+10	1.940E+09	1.337E+08	5.782E+06
17.	1.015	177.209	.075	1.296E+11	1.357E+11	8.074E+10	2.696E+10	5.958E+09	6.116E+08	3.796E+07
18.	1.195	179.582	.077	1.247E+11	1.288E+11	1.075E+11	4.483E+10	1.479E+10	2.409E+09	2.182E+08
19.	1.382	186.796	.079	1.177E+11	1.189E+11	1.232E+11	6.956E+10	2.531E+10	6.983E+09	9.471E+08
20.	1.569	187.279	.079	1.138E+11	1.108E+11	1.242E+11	9.519E+10	4.048E+10	1.528E+10	3.160E+09
21.	1.758	189.430	.258	1.135E+11	1.115E+11	1.174E+11	1.123E+11	6.204E+10	2.428E+10	7.581E+09
22.	1.952	193.410	.080	1.152E+11	1.156E+11	1.099E+11	1.177E+11	8.548E+10	3.728E+10	1.574E+10
23.	2.145	192.754	.083	1.154E+11	1.164E+11	1.079E+11	1.146E+11	1.030E+11	5.636E+10	2.353E+10
24.	2.343	198.306	.083	1.138E+11	1.134E+11	1.106E+11	1.088E+11	1.110E+11	7.788E+10	3.494E+10
25.	2.539	195.925	.083	1.123E+11	1.103E+11	1.128E+11	1.056E+11	1.072E+11	9.526E+10	5.211E+10
26.	2.741	202.260	.089	1.123E+11	1.104E+11	1.115E+11	1.065E+11	1.070E+11	1.047E+11	7.191E+10
27.	2.940	198.894	.086	1.134E+11	1.126E+11	1.092E+11	1.089E+11	1.038E+11	1.066E+11	8.876E+10
28.	3.144	204.391	.085	1.136E+11	1.135E+11	1.072E+11	1.089E+11	1.035E+11	1.045E+11	9.905E+10
29.	3.346	201.656	.086	1.127E+11	1.121E+11	1.092E+11	1.065E+11	1.052E+11	1.019E+11	1.025E+11
30.	3.552	205.712	.085	1.116E+11	1.105E+11	1.104E+11	1.050E+11	1.058E+11	1.011E+11	1.018E+11
31.	3.756	204.360	.267	1.111E+11	1.103E+11	1.097E+11	1.058E+11	1.044E+11	1.021E+11	9.988E+10
32.	3.964	207.900	.088	1.110E+11	1.107E+11	1.079E+11	1.072E+11	1.030E+11	1.029E+11	9.983E+10
33.	4.175	211.485	.084	1.104E+11	1.103E+11	1.071E+11	1.070E+11	1.032E+11	1.021E+11	9.977E+10
34.	4.390	214.613	.085	1.093E+11	1.088E+11	1.073E+11	1.054E+11	1.043E+11	1.007E+11	9.906E+10
35.	4.613	223.161	.083	1.083E+11	1.074E+11	1.074E+11	1.044E+11	1.042E+11	1.001E+11	9.742E+10
36.	4.845	232.241	.081	1.078E+11	1.072E+11	1.064E+11	1.044E+11	1.025E+11	1.000E+11	9.377E+10
37.	5.124	278.689	.079	1.076E+11	1.073E+11	1.043E+11	1.043E+11	1.004E+11	9.804E+10	8.893E+10
38.	5.403	279.226	.083	1.068E+11	1.061E+11	1.042E+11	1.016E+11	9.910E+10	9.160E+10	8.234E+10
39.	5.682	278.757	.083	1.060E+11	1.052E+11	1.034E+11	9.922E+10	9.448E+10	8.408E+10	6.902E+10
40.	5.960	278.217	.084	1.056E+11	1.049E+11	1.010E+11	9.656E+10	8.618E+10	7.337E+10	5.245E+10
41.	6.194	234.000	.265	1.046E+11	1.035E+11	9.826E+10	9.043E+10	7.707E+10	5.854E+10	4.049E+10
42.	6.431	236.616	.084	1.031E+11	1.013E+11	9.452E+10	8.220E+10	4.630E+10	4.630E+10	3.023E+10
43.	6.708	276.958	.084	1.011E+11	9.813E+10	8.747E+10	7.135E+10	5.287E+10	3.587E+10	1.922E+10
44.	6.985	276.557	.084	9.801E+10	9.330E+10	7.621E+10	5.846E+10	4.042E+10	2.542E+10	9.509E+09
45.	7.261	276.297	.084	9.359E+10	8.610E+10	6.484E+10	4.634E+10	3.072E+10	1.513E+10	4.857E+09
46.	7.537	276.194	.083	8.902E+10	7.913E+10	5.574E+10	3.673E+10	2.121E+10	7.960E+09	6.044E+09
47.	7.813	275.968	.084	8.572E+10	7.529E+10	4.954E+10	2.947E+10	1.326E+10	6.852E+09	7.240E+09
48.	8.088	275.420	.084	8.319E+10	7.348E+10	4.646E+10	2.436E+10	1.078E+10	8.817E+09	5.025E+09
49.	8.363	274.723	.084	8.042E+10	7.143E+10	4.516E+10	2.355E+10	1.287E+10	8.564E+09	2.067E+09
50.	8.597	234.145	.063	7.749E+10	6.884E+10	4.530E+10	2.731E+10	1.697E+10	7.171E+09	8.775E+08

FIGURE 6.6 SAMPLE HISTORICAL LISTING OF VARIABLES FROM SCRIBE

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PERIODIC PRINT
N= 300, JSTAN= 22, TIME= 5.037E-05, CALC TIME= 483.290 SECS, JTS= 14 DTNH= 1.189E-07 SPAX= 1.859E+09 JSMAX= 4

STOP CRITERION
**** CRITERION FOR STOP ****
N = 300, JCYCS = 300, TIME = 5.037E-05, TS = 8.000E-05, X(JSMAX) = 2.559E+00, CKS = 3.000F+01, LSUB(7)= 0, DTNH = 1.189E-07

SHEAR2 OUTPUT
K= 21 J= 21 IN3= 16 ROT= 0. EN= .841E+01 YAU= .698E+00 EP= .745E+00
NG= 4
CN= .513E+01 .266E+01 .133E+01 .595E+00 .222E+00 .635F-01 .124E-01 .141E-02
CL= .101E+00 .242E+00 .440E+00 .717E+00 .110E+01 .151E+01 .189E+01 .225E+01
NG= 5
CN= .159E+01 .102E+01 .576E+00 .276E+00 .107E+00 .307E-01 .591E-02 .456E-03
CL= .103E-01 .247E-01 .449E-01 .732E-01 .113E+00 .168E+00 .246E+00 .354E+00
NG= 6
CN= .169E+01 .109E+01 .615E+00 .293E+00 .112E+00 .322E-01 .619E-02 .484E-03
CL= .888E-02 .213E-01 .387E-01 .631E-01 .972E-01 .145E+00 .212E+00 .305E+00
TOY PL STRAIN = 0.000 0.000 .256 .224 .219
TAUZ= 0.00000 0.00000 0.00000 .697120 .000435 .000293

BFRAC73 OUTPUT
FRAG N= 4.68E+01 1.142E+01 1.162E+01 5.284E+01 5.284E+02 FF= 7.195E-01, CYCLE= 13
J= 1 C1= 2.945E-01 2.923E-01 2.923E-01 2.931E-01 2.931E-01 FRF= 5.229E-02 4.174E-01 4.174E-01 2.349E-01
K= 2 CB= 5.332E-01 5.332E-01 5.332E-01 5.332E-01 5.332E-01 LAUZ= 2.829E-01 8.006E-02 8.006E-02 3.654E-01 3.654E-01
VVA= 1.343E-02 3.452E-03 3.452E-03 1.611E-02 1.611E-02

```

FIGURE 6.7 MISCELLANEOUS MESSAGES AND LISTINGS GENERATED DURING CALCULATIONS

a message containing the criteria used for stopping the run, as in Figure 6.7. In this case the halt occurred when $N = JCYCS$. Other possibilities are $TIME \geq TS$, $X(JSMAX) \geq CKS$, $LSUB(7) = 1$, and $DTNH < 1.E - 12$. $LSUB(7)$ is set to 1 in HSTRESS and FMELT to trigger an error stop.

Several material property subroutines provide regular listings in the cycle just preceding an EDIT. The samples in Figure 6.7 are from SHEAR2 and BFRACT3. EXPLODE also prints a line whenever the detonation is completed at a cell. If the iterations do not converge in CAP1, BFRACT3, REBAR, PEST, EQSTPF, TSQE, BECOM, or DFRACT, an error message and some information about the cause and location of failure is given. REZONE lists all its major operations so that difficulties can be traced.

Appendix A

THERMAL ENERGY DEPOSITION

In SRI PUFF, radiant energy is deposited gradually into the finite difference cells over a time corresponding to the source duration. This appendix gives some background on source characteristics, radiation absorption information for materials, and procedures for depositing the energy into the material layers for both normal and oblique incidence of the radiation. These processes are all treated in the DEPOS subroutine. The interpolation procedure used with depth-dose profiles and contained in SCATTO is also described.

Specific information for constructing the input deck for radiation problems is in Section 5.4, and sample input is given in Appendix C.

Radiation Absorption Characteristics

The radiation absorption calculations in PUFF provide a means for determining the radiant energy absorbed in each finite difference cell for x-ray sources. Only absorption associated with the photoelectric effect is considered in the calculations. If scattering and fluorescence are important, as they are for photon energies larger than a few keV, an appropriate deposition code like FSCATT should be used to obtain a depth-dose profile for the PUFF calculations.

The geometry assumed in the absorption calculations is planar. Cylindrical or spherical geometries must be treated by means of a depth-dose profile or by detailed initialization of internal energy (EHL) or the SS array through a NAMELIST statement.

Typical radiation absorption characteristics associated with the photoelectric effect are illustrated in Figure A.1. The sharp discontinuities in the absorption occur at photon energies related to the orbits of the electrons. The discontinuity farthest to the right is called the K edge because it is associated with electrons in the K shell. The next edges to the left are L, M, and N edges. Between the edges the absorption function varies smoothly, approximately following the function

$$\sigma_a \propto (h\nu)^{-3} \quad (\text{A.1})$$

where σ_a is the mass absorption coefficient and $h\nu$ is the photon energy (ν is frequency and h is Planck's constant). In standard tables, such as those of McMasters et. al.⁴¹ and Fisher and Wiehe,⁴² the absorption coefficient is expanded in the following form between edges:

$$\ln \sigma_a = A_0 + A_1 w + A_2 w^2 + A_3 w^3 \quad (\text{A.2})$$

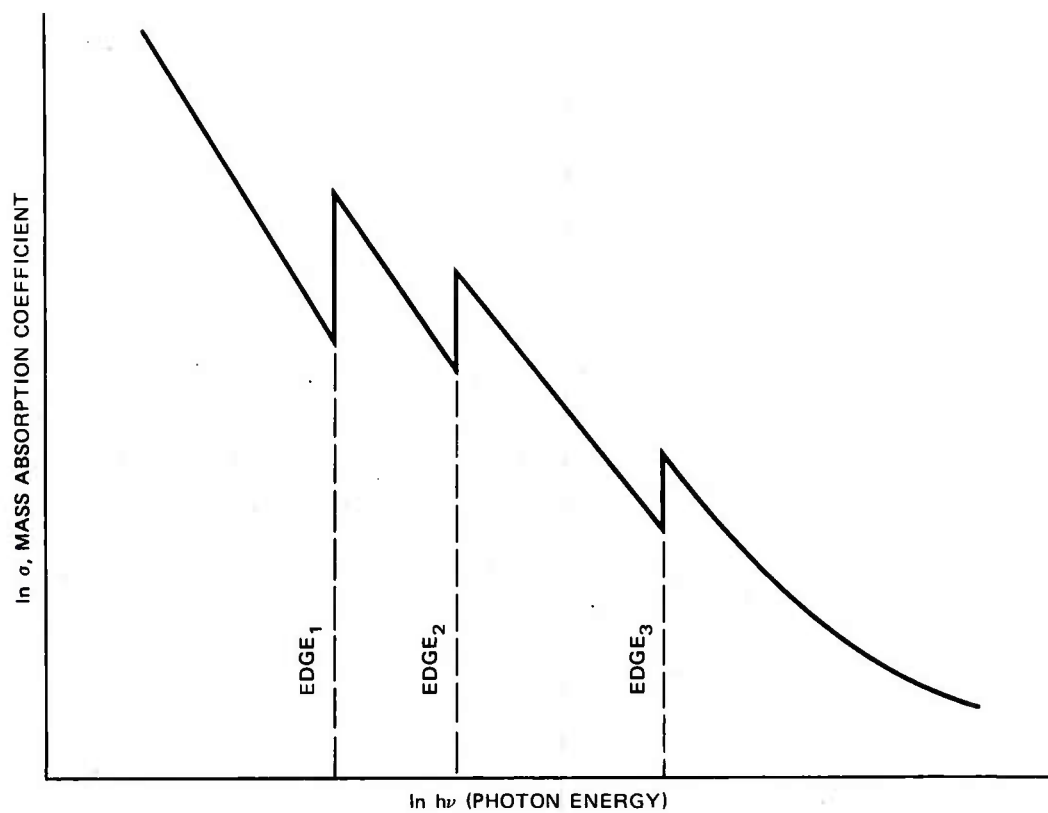
where σ_a the mass absorption coefficient, barn/atom

$$\begin{aligned} w &= \ln(h\nu) \\ h\nu &= \text{photon energy, keV} \\ A_0 \dots A_3 &= \text{coefficients of the fit.} \end{aligned}$$

Because the absorption coefficient follows Eq. (A.1), A_1 is approximately equal to -3.

For absorption by the photoelectric effect, there is an exponential attenuation of energy through a layer of material. The fraction of the fluence I_0 (with a specific photon energy) transmitted through a thickness ΔX is

$$\frac{I}{I_0} = \exp (-\mu_a \Delta X) \quad (\text{A.3})$$



MA-6802-4

FIGURE A.1 TYPICAL VARIATION OF PHOTOELECTRIC MASS ABSORPTION COEFFICIENT WITH PHOTON ENERGY

where μ_a is the linear absorption coefficient with units of 1/cm appropriate to the incident photon energy (Here we are considering normal incidence only; Section 4 treats the case of oblique incidence.) The coefficient μ_a is related to σ_a as follows.

$$\mu_a = \frac{\rho C_b N_a \sigma_a}{A_w} = 0.602252 \frac{\rho \sigma_a}{A_w} \quad (A.4)$$

where ρ = density, g/cm³

$C_b = 10^{-24}$ cm²/barn, a conversion factor

$N_a = 6.02252 \times 10^{23}$, Avogadro's number, atom/mole

A_w = atomic weight, g/mole

σ_a = mass absorption coefficient, barn/atom.

With the coefficients A_0, \dots, A_3 and Eqs. (A.2) to (A.4), the attenuation and absorption of energy can be calculated for any source with a single photon energy.

$$\mu_a = 0.602252 \frac{\rho}{A_w} \sum_{i=0}^3 A_i [\ln(h\nu)]^i \quad (A.5)$$

Use of these absorption characteristics to treat attenuation of radiation from a source with a range of photon energies is described in the following sections of this appendix.

For multiple constituent materials, absorption coefficient information is entered for each constituent. Such materials may be either mixtures or compounds of any kind. Common examples are a metal alloy or an epoxy resin. In such materials the absorption coefficients are defined and entered in the usual fashion for each constituent, and then a composite absorption coefficient is calculated in the program. The composite absorption coefficient is

$$\mu_a = 0.602252 \sum_{n=1}^{N_c} \frac{\rho_n}{A_{wn}} \sum_{i=0}^3 A_{in} \left[\ln(h\nu) \right]^i \quad (A.6)$$

where N_c = the number of constituents

A_{wn} = the atomic weight of the nth constituent

A_{in} = the coefficients in the absorption function for the nth constituent.

Here ρ_n is the weight fraction of the nth constituent times the composite density. Hence

$$\rho = \sum_{n=1}^{N_c} \rho_n \quad (A.7)$$

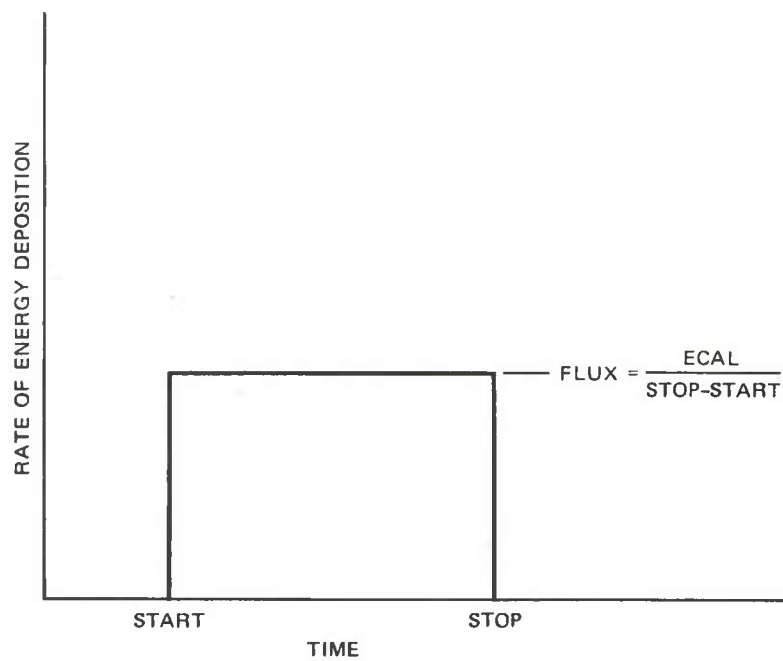
Radiation Sources

Since the radiation sources permitted in the program are all steady state, only an emittance history and a single emittance spectrum are required. The emittance or flux history is that shown in Figure A.2, with an abrupt start, a constant value for the duration of deposition, and an abrupt stop.

Two types of sources are accounted for in the absorption calculations: an arbitrary spectrum and one made up of several black body radiators. For the arbitrary spectrum the user divides the energy into several energy packets, each at a specific photon energy, and pairs of values of energy and $h\nu$ (photon energy) are read in.

For the black body source, some standardization is possible because of the simple relation between radiant emittance and the photon energy. According to Sears⁴³ for a black body of unit energy, the radiant emittance dW is

$$dW = \frac{15}{\pi^4} \left(\frac{\omega^3}{e^{\omega} - 1} \right) d\omega \quad (A.8)$$



G8-6586-7

FIGURE A.2 HISTORY OF RADIATION SOURCES CONSIDERED IN THE PROGRAM

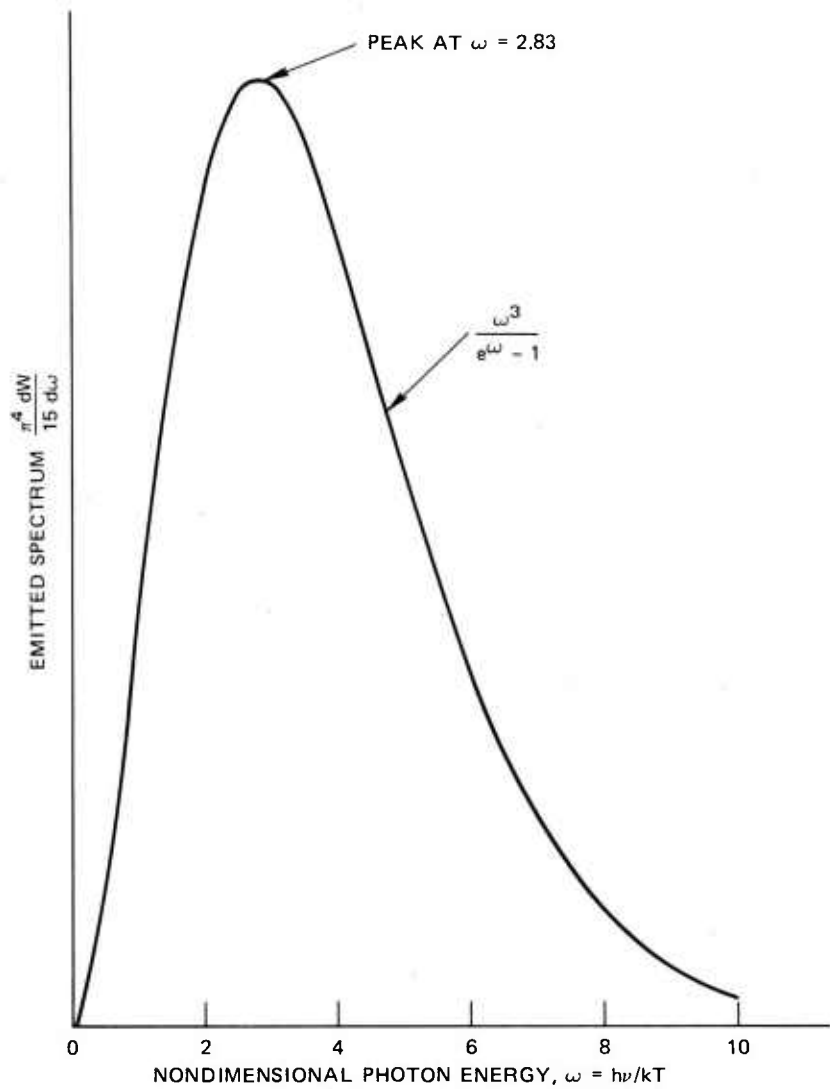
where

- $\omega = h\nu/kT$, a nondimensional quantity proportional to photon energy
- h = Planck's constant
- ν = frequency of the photons
- $h\nu$ = photon energy, usually in keV
- k = Boltzmann constant
- T = Kelvin temperature
- kT = temperature in energy units, usually keV (Planckian temperature).

The variation of radiant emittance with photon energy is shown in Figure A.3. The total emittance of the black body is the area under the curve. For calculations in the program, the spectrum has been divided into 95 energy packets. Each energy packet is located at a discrete $h\nu$ value (BBDY in the program). The energy (EIBB) in each packet was determined by integrating the area under the emittance curve over appropriate ranges of $h\nu$ to determine ΔW from Eq. (A.8) (as shown in Figure A.4). The black body spectrum is completely specified by a Planckian Temperature kT (TEMP in the program, keV) and the total fluence (ECAL, cal/cm²).

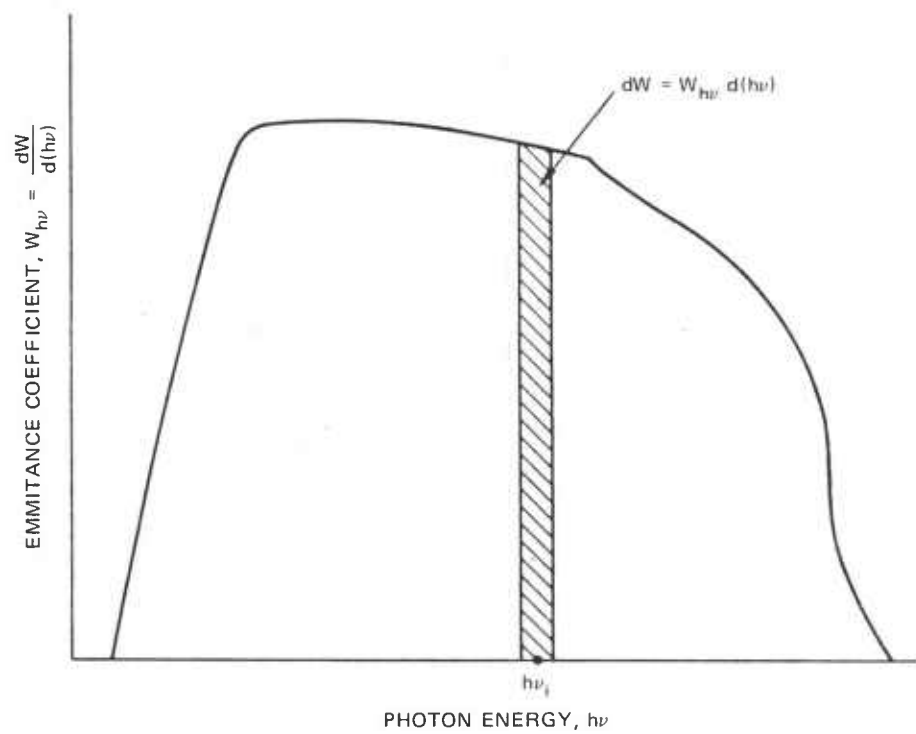
Deposition Computations

Radiation deposition by means of an absorption calculation is provided for two types of sources: a black body or bodies, and an arbitrary spectrum. The deposition of radiation from either a black body or an arbitrary spectrum is obtained by computing the absorption of each energy packet (located at a discrete value of $h\nu$) using the absorption coefficient corresponding to that value of $h\nu$. The penetration of the radiant energy into the material is given by an exponential relation as shown in Figure A.5. Then within a cell thickness X , the increment of energy is



GA-6586-8

FIGURE A.3 EMITTANCE SPECTRUM FOR BLACK BODY



G8-6586-6

FIGURE A.4 SPECTRUM OF A RADIATION SOURCE

$$\Delta E = E_1 \left(1 - e^{-\mu_a \Delta X} \right) \quad (A.9)$$

where

E_1 = the amount of energy reaching the left face of the cell

ΔX = the thickness of the cell.

Because μ_a is a function of $h\nu$, Eq. (A.9) can be used only for particular values of $h\nu$, that is, for energy packets located at the $h\nu$ values. To provide reasonable accuracy in the deposition, it is necessary to provide a large number of $h\nu$ values (109 values of $h\nu$ are permitted in the present dimension statement). The large number of $h\nu$ values is desirable because the program selects a single value of μ_a for each abscissa, and the function of μ_a versus $h\nu$ is extremely uneven, as shown in Figure A.1.

In DEPOS the deposition into the grid is accomplished by inserting the energy from the various spectral sources into an array SS for each cell. During the wave propagation calculations, this energy will be gradually inserted into the internal energy in the cell. A value of SS is computed for each cell and for each source. The equation for the energy deposited in the j th cell in an increment of time Δt is given by

$$\Delta E_j = C_c \frac{E_{R,j}^n \Delta t}{Z_j \Delta T^n} \quad (A.10)$$

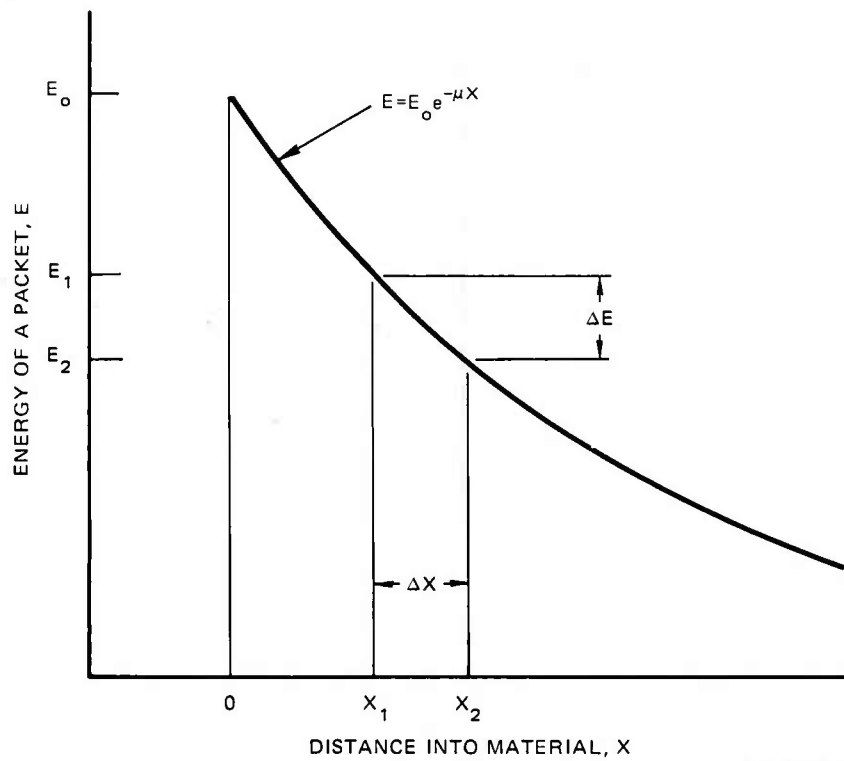
where

$E_{R,j}^n$ = the total energy in cal/cm^2 to be deposited in the j th cell from the n th source

C_c = a conversion factor, 4.186×10^7 erg/cal

Z_j = the mass of the j th cell, g/cm^2

ΔT^n = the duration of the n th source.



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FIGURE A.5 PENETRATION OF ENERGY INTO A MATERIAL

Then the deposited energy ΔE_j is in erg/g. The array SS is defined to include all the constant quantities in Eq. (A.10), that is, all except Δt .

$$SS_j^n = \frac{C_c E_{R,j}^n}{Z_j \Delta T^n} \quad (A.11)$$

During the wave propagation calculations, the manipulations with the array SS are conducted in the function SSCALH.

Radiation Deposition at Oblique Incidence

For a monoenergetic source at normal incidence, the radiation is absorbed into a material according to the standard exponential law:

$$E = E_o e^{-\mu_a X} \quad (A.12)$$

where

E_o = the incident energy

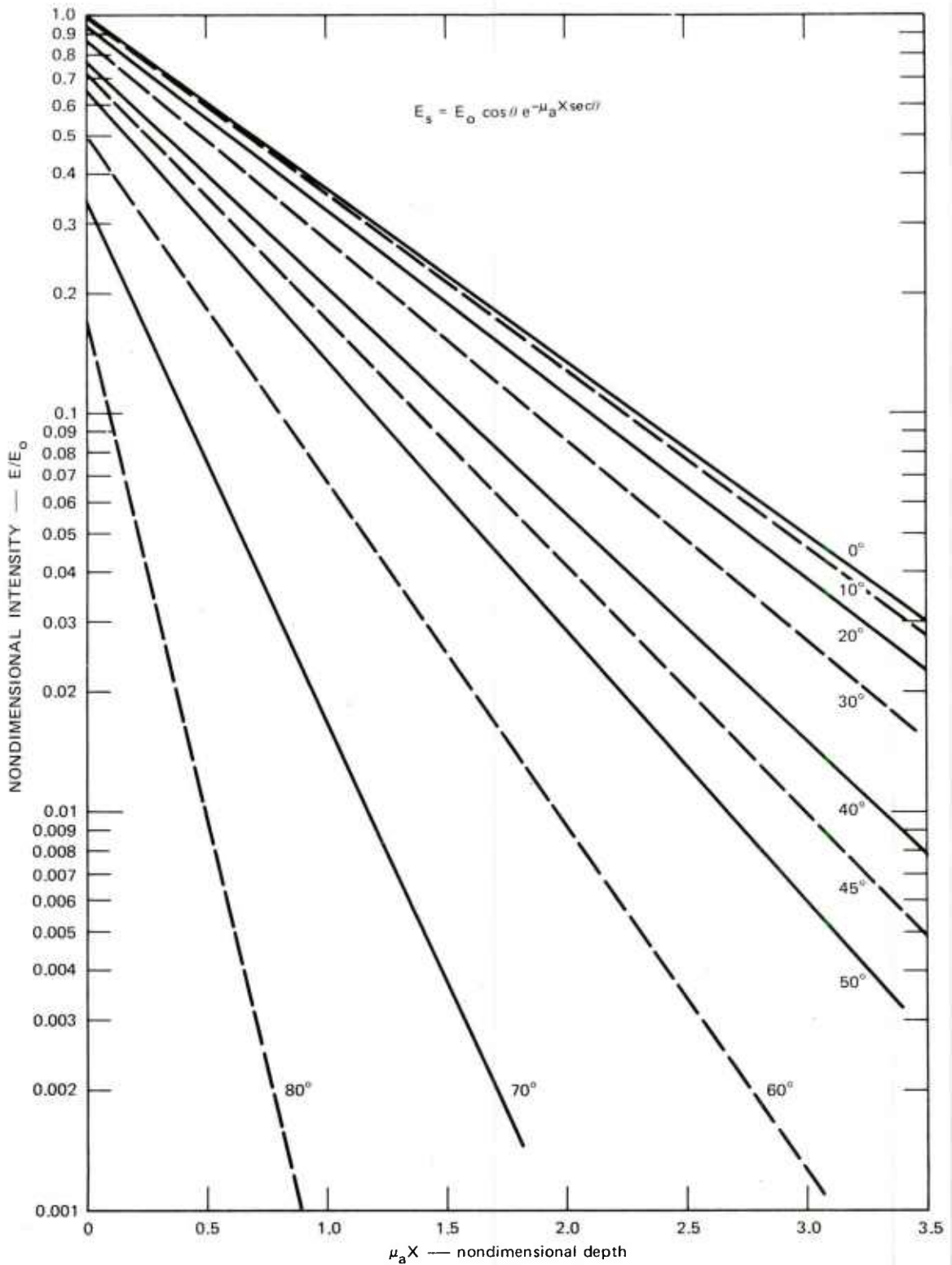
E = the intensity at any depth, X .

If the incidence is not normal then Eq. (A.12) is modified in two ways: the intensity at the front is reduced by the cosine of the angle, and the depth is increased by the cosine. Thus the equation becomes

$$E_s = E_o \cos \theta e^{-\mu_a X \sec \theta} \quad (A.13)$$

where θ is the angle from normal incidence. Equation (A.13) is shown in Figure A.6.

The absorbed energy in erg/g is determined as the difference between incident and transmitted fluence, divided by the mass. Considering a small cell of material with lengths ΔX , ΔY , and ΔZ , the incident fluence is



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FIGURE A.6 RADIATION INTENSITY AS A FUNCTION OF DEPTH FOR SEVERAL INCIDENT ANGLES

$$E_{si} \Delta Y \Delta Z = E_o \cos \theta e^{-\mu_a X_1 \sec \theta} \Delta Y \Delta Z$$

and the mass is

$$Z_j = \rho \Delta X \Delta Y \Delta Z$$

Therefore, the absorbed energy is

$$\begin{aligned} \Delta E_a &= \frac{(E_{si} - E_{s2}) \Delta Y \Delta Z}{\rho \Delta X \Delta Y \Delta Z} \\ &= \frac{E_o \cos \theta e^{-\mu_a \Delta X \sec \theta}}{Z_j} \end{aligned} \quad (A.14)$$

Depth-Dose Profile Interpolation

When a depth-dose profile for the radiation is provided by a table of energy-distance values, the energy for each PUFF cell is determined by interpolation. These interpolations are performed in the subroutine SCATTO. The depth-dose profile may represent depositions from an electron beam, a laser, or an x-ray source, and may be determined either experimentally or analytically. To account for x-ray absorption by scattering, fluorescence, and the photoelectric effect, we have used the FSCATT code of Fisher and Wiehe.⁴² The FSCATT results provide deposited energy (e.g., cal/g) at coordinate points in a finite difference grid for a unit of radiant energy (e.g., 1 cal/cm²). All depth-dose profiles are assumed to have this form.

For PUFF calculations the deposited energy is an average quantity over the cell thickness, whereas the depth-dose profile provides energies at discrete depths. The PUFF cell energies are derived by interpolating between points in the depth-dose profile and then integrating over the PUFF cell dimensions.

The approach taken for the interpolation is to assume that the deposited energy is representable by a smooth function that can be defined by energy values at the depths given in the depth-dose profile. This function is then integrated over each PUFF cell dimension to find the energy deposited therein. The energy is assumed to span across three depths in the given profile and to have the form of a parabola in a semi-log plot. An expression for this parabolic form is

$$E_s = E_{s1}^{\xi_1} \cdot E_{s2}^{\xi_2} \cdot E_{s3}^{\xi_3} \quad (\text{A.15})$$

where E_s = the energy at any depth

E_{s1}, E_{s2}, E_{s3} = energies at the given depths in the depth-dose profile

$$\xi_1 = \frac{(X - X_2)(X - X_3)}{(X_1 - X_2)(X_1 - X_3)}$$

$$\xi_2 = \frac{(X - X_1)(X - X_3)}{(X_2 - X_1)(X_2 - X_3)}$$

$$\xi_3 = \frac{(X - X_1)(X - X_2)}{(X_3 - X_1)(X_3 - X_2)}$$

X_1 = depths in the depth-dose profile.

The form of Eq. (A.15) is suggested by the shapes of deposition curves that are essentially exponential, except near material boundaries, where they may be more rounded. The energy (E'_j) deposited in the j th PUFF cell per unit of fluence is the average of E_s between the cell coordinates, X_j and X_{j+1} . This average is expressed by the integral

$$E'_j = \frac{1}{X_{j+1} - X_j} \int_{X_j}^{X_{j+1}} E_s \, dX \quad (\text{A.16})$$

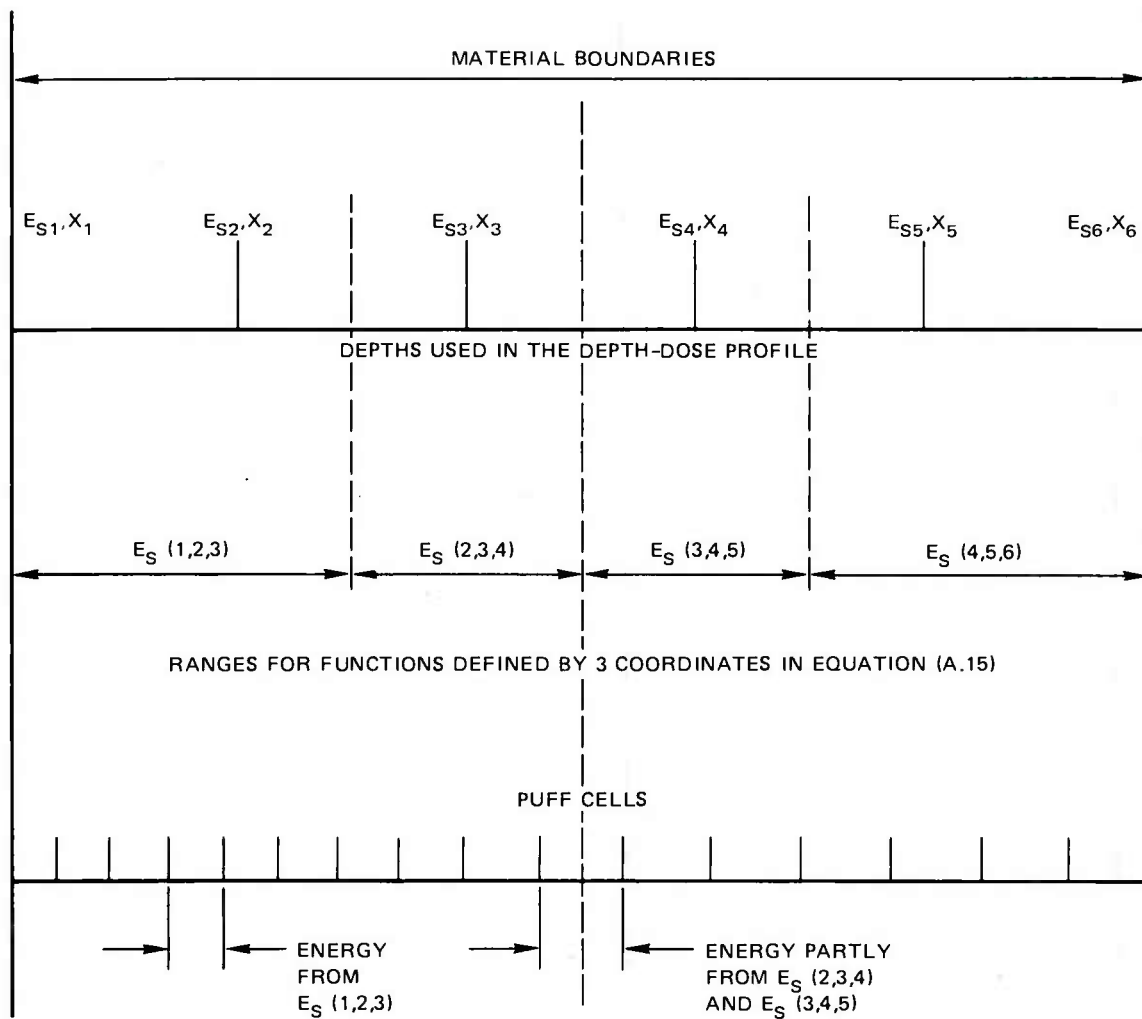
This integration is performed numerically using Simpson's rule.

The function in Eq. (A.15) best represents the variation of deposited energy in some middle portion of the three depths used in the interpolation. Therefore, it was decided to use the function defined by three depths only from the middle of the first pair of depths to the middle of the second pair. Figure A.7 shows the profile depths that contribute to the deposition in each PUFF cell.

The final step in the deposition is to initialize the SS array in a manner similar to that described above for deposition computations. The energy in each PUFF cell, E'_j , is based on one unit of radiated energy. Therefore, the actual absorbed energy in any cell from a source with a total fluence of E_{cal} is $E'_j \cdot E_{cal}$. Then the expression for computing values for the SS array is

$$SS_j^n = \frac{C_c E'_j \cdot E_{cal}}{\Delta T^n}$$

The SS array is used in the function SSCALH to provide energy increments for each cell during the propagation calculations.



GA-8152-4A

FIGURE A.7 PATTERNS FOR INTERPOLATION OF THE RADIANT ENERGY IN A DEPTH-DOSE PROFILE TO OBTAIN ENERGIES FOR PUFF CELLS

Appendix B

CALCULATIONS FOR EXPLOSIVES

This appendix outlines a simple detonation theory based on standard references such as Taylor.⁴⁴ Then the types of detonation provided in PUFF, the input required, and the algebra of the code calculations are described.

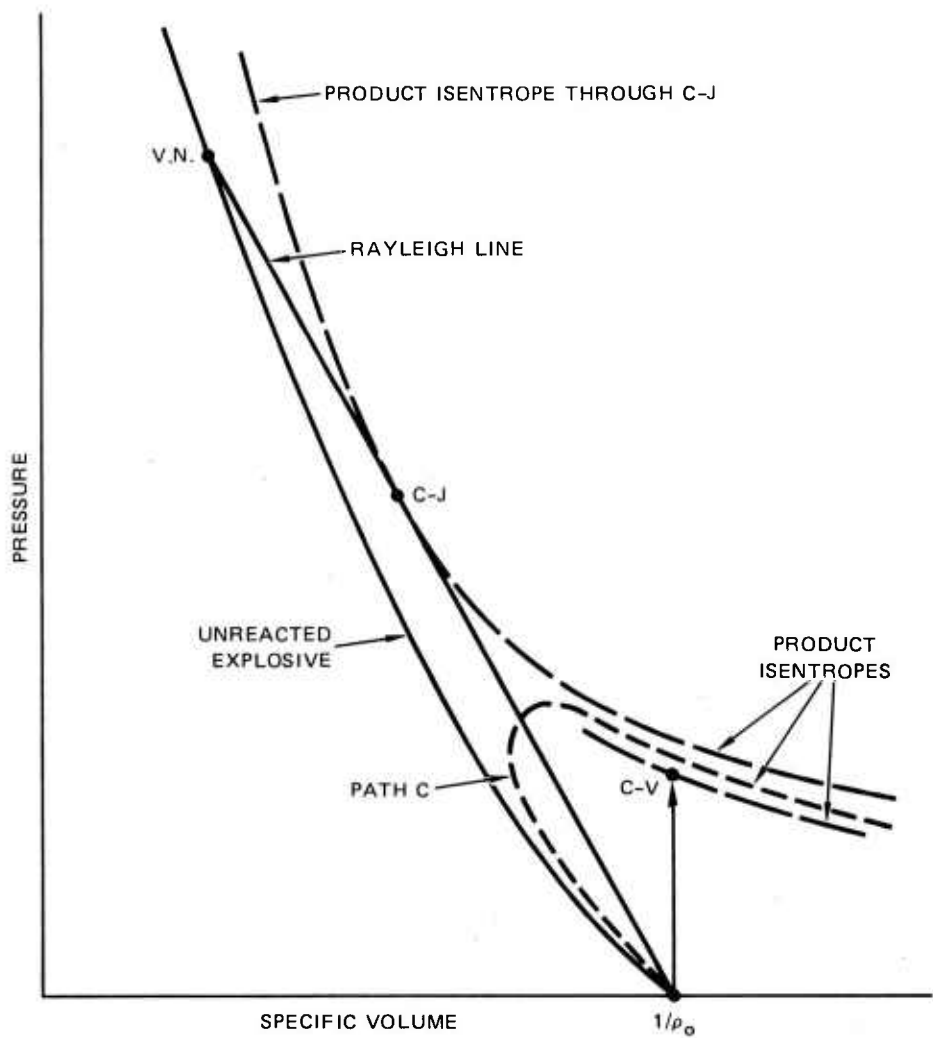
Background on Detonation Processes

Three substances are involved in a detonation process: the unreacted explosive, the reacting explosive, and the product gases. Here we will presume that the unreacted explosive and the product gases can be represented by equations of state with the pressure-volume isentropes shown in Figure B.1. During detonation, the chemical energy in the explosive is transformed to internal energy and the state point moves from the unreacted curve to the product curve of Figure B.1. In Chapman Jouguet detonation theory, the reaction occurs within the shock front. In a steady detonation, the material follows a Rayleigh line from the initial density to a point of tangency on the products curve as shown. The point of tangency is the Chapman-Jouguet or C-J point. The pressure, volume, and energy at this point are labeled P_{CJ} , V_{CJ} , and E_{CJ} . If the product gases are assumed to follow a polytropic gas equation of state, that is,

$$PV^\gamma = \text{constant} \quad (\text{B.1})$$

then relations for the detonation velocity (D_x), P_{CJ} , V_{CJ} , E_{CJ} , and the particle velocity (u_{CJ}) can be derived. These are all derived from the polytropic gas relations, Hugoniot jump conditions, energy conservation, and the condition of tangency at the C-J point.

$$D_x = \sqrt{2Q_x(\gamma + 1)(\gamma - 1)} \quad (\text{B.2})$$



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FIGURE B.1 PRESSURE-VOLUME PATHS FOLLOWED IN DETONATION PROCESS

$$P_{CJ} = 2Q_x(\gamma - 1) \rho_o \quad (B.3)$$

$$V_{CJ} = \frac{\gamma}{\rho_o(\gamma + 1)} \quad (B.4)$$

$$E_{CJ} = \frac{2Q_x \gamma}{\gamma + 1} \quad (B.5)$$

$$u_{CJ} = \sqrt{\frac{2Q_x(\gamma - 1)}{\gamma + 1}} \quad (B.6)$$

where Q_x = the energy of the explosive

ρ_o = the initial density.

The polytropic gas exponent is related to the Grüneisen ratio as follows

$$\gamma = \Gamma + 1 \quad (B.7)$$

For many common explosives, γ values range from 2.5 to 3.0. This exponent describes the product gas isentrope adequately down to a few kilobars. For lower pressures, the apparent γ value decreases gradually to about 1.5 at ambient conditions.

Besides the Chapman-Jouguet process, several other detonation processes may occur in explosives. Von Neumann suggested that in a steady-state running detonation, the pressure in the shock rises to the point V.N. in Figure B.1 and then reduces gradually to C-J as the chemical reaction occurs. Path C is typical of computed pressure-volume paths followed during the buildup to a steady-state detonation. Here the chemical reaction is occurring during the loading by the stress wave. If the explosion occurs without a change in volume, the vertical path to the constant-volume point C-V is followed. The Chapman-Jouguet, von Neumann, constant-volume, and various gradual detonation processes have all been used to represent explosive phenomena. Only the Chapman-Jouguet and constant-volume processes are currently available in PUFF.

The detonation type used in the calculation should match as nearly as possible the explosive behavior and geometry being considered. For example, if a block of explosive next to a plate is detonated at a point

on the block opposite the plate, the detonation front will reach the plate as a plane wave; this process should be simulated as a running detonation. If the detonation occurs such that the wave front sweeps past the plate, however, a constant-volume explosion gives a better representation of the impulse applied to the plate (the actual wave front is not moving in the direction of motion in PUFF). In some problems the stress histories in the explosive are not important (as in the impact of an explosively driven flyer plate); then a constant-volume calculation will adequately represent the impulse applied by the explosive.

Computation of Detonation Processes with the Subroutine EXPLode

The Chapman-Jouguet and constant-volume detonation processes are incorporated into the EXPLode subroutine. This routine may be called to perform three different functions: reading input, initializing cells, and computing the pressure for the running detonation.

The input for an explosive calculation includes Q_x , X_D , and b and is read during the first call to EXPLode from GENRAT. If a constant-volume explosion is desired, only the chemical energy Q_x is provided. X_D is the initiation point for a running detonation and b is the number of cells over which a detonation front is spread. Nominal values of b are 2 to 4.

At the second call to EXPLode, the energy and density of cells containing explosive are initialized. This call is made from GENRAT during the cell layout process. For a constant-volume explosion, the internal energy is equated to Q_x , and F_B (the detonated fraction) is set to 1.0 to show that detonation has taken place. The calculations of pressure during the propagation process are then all treated in a section of EQST.

For a running detonation, only cells near the detonation point are initialized at the second call to EXPLode. The reacted fraction F_B of a cell is computed based on the distance of the cell midpoint from the initiation point.

$$F_B = 1 - \frac{|\bar{X} - X_D|}{b\Delta X} \quad (B.8)$$

where \bar{X} = the cell midpoint

ΔX = the cell length in the direction of propagation.

From eq. (B.8) it appears that the cell midpoint must be within a distance $b\Delta X$ of the initiation point for any initiation to occur. For $F_B > 0$, the pressure, density, and internal energy are augmented to represent a point along the C-J detonation path in Figure B.1. Hence

$$P = P_{CJ} F_B \quad (B.9)$$

$$\rho = \frac{\rho_o}{1 + F_B (V_{CJ} \rho_o - 1)} \quad (B.10)$$

$$E = Q_x + (E_{CJ} - Q_x) F_B \quad (B.11)$$

This energy calculation appears adequate, although it is not justified analytically.

The third call to EXPLODE is made in HSTRESS and only for a running detonation. The purpose of the call is to compute pressure and energy during the reaction process; the pressure of fully detonated material is treated by EQST. First, the time t_B to begin burning is computed.

$$t_B = \frac{|\bar{X} - X_D| - b \Delta X}{D_X} \quad (B.12)$$

The fraction detonated is then

$$F_B = \frac{(t - t_B) D_X}{b \Delta X} \quad (B.13)$$

where t is the current problem time. Because of the absolute value sign in Eq. (B.12), the detonation can proceed in either direction from the initiation point. Given the detonated fraction F_B , the pressure and energy are computed both from the usual polytropic gas relations and as fractions of the C-J values. The pressure and energy values for the cell are taken as the maxima from these two calculations.

Appendix C

DESCRIPTION OF INPUT

This appendix provides some sample input decks and supplements the input description provided in Section 5. The construction and use of a data bank is outlined; the bank can be a permanent or temporary file containing material properties or other data. A procedure for reading special data through a NAMELIST statement is given, and the method for entering variables to obtain historical listings of any array quantity at any cell is described. The meaning of the indicator NVAR is given to aid in incorporating new material models, in calculating with models having large numbers of variables, or in getting data from large models.

Data Banks

A data bank for PUFF is a file containing some portion of the input for a problem. Specifically, the data may be card images representing the general running information of Section 5.1, a complete set of properties for a material, x-ray radiation absorption coefficients for a material, an x-ray spectrum, or a depth-dose profile for a radiation problem. Sample data banks are shown in Figure C.1 and C.2. After describing the banks, we outline their use in setting up problems.

The two banks in Figures C.1 and C.2 were constructed by inserting them like data decks for reading by GENRAT. The first line of the data must read

_DATA or _ABS DATA

where either word starts in column 2. On reading the word "DATA", GENRAT places the next card images up to an end-of-file (the 7/8/9 card) on Tape 4, whereas "ABS DATA" indicates a write to Tape 2. Material properties data, general running information, spectral data, and depth

-DATA- IN COLUMNS 2-5 INDICATES A DATA BANK FOR TAPE 4

```

HEADING      SHOCKEY
NTEDT =      0 NJEOT =      1 NREZON =      0 NALPHA =      1
JEDIT =      14 16 18 20 21 22 23 24 26 28
NEDIT =      10 JCYCS =      200 CKS =      10. TS =      1.
NMTRLS =      2 MATFL =      1 UZERU =      0.

1145 AL      RHOS =      2.784 CFP = 000 DPY = 503
EQST =      8.560E+11 0. 1.000E+11 2.1 2.1
BAUSCH =      3.000E-02 4.000E+10 4.000E+10 2.000E-01
YIELD =      4.130E+09 3.000E+11
VISC =      4.0 0.05 0.05
EMELT =      6.600E+09 5.000E+09 0. 1.0 0.25

1145 AL HOT  RHOS =      2.70452 CFP = 010 DPY = 003
EQST =      8.560E+11 0. 1.000E+11 2.1 2.1
DFR1 =      -0.00625 -4.000E+09 1.000E-04 2.000E+12-3.000E+09 0.960E+09
YIELD =      2.000E+09 3.000E+11
VISC =      4.0 0.05 0.05
EMELT =      6.600E+09 5.000E+09 0. 1.0 0.25

ARMCO SH BAND RHOS =      7.85E0 CFP= 030 DPY= 002 NVAR = 58 NCON= 0
EQST=      1.589E+12 5.170E+12 7.360E+10 1.69E0 0.25E0 5.170E+13
SH2      3.000E+01 .2000E+00 1.100E-02 3.000E-04 0.17 0.070E+00 0.070E+00
      1.4 3.000E-08 3.000E+08 6. .2 .17 7.000E+09
NSIZE      0 0 0 8 8 8 0 0 0
MELT =      1.085E+10 6.460E+09 5.700E-01 7.000E-01 1.850E-01
YIELD =      2.000E+09 8.190E+11

HF-1 SH BAND RHOS =      7.85E0 CFP= 030 DPY= 002 NVAR = 58 NCON= 0
EQST=      1.589E+12 5.170E+12 7.360E+10 1.69E0 0.25E0 5.170E+13
SH2      3.000E+01 .2000E+00 1.100E-02 1.000E-03 0.17 0.070E+00 0.070E+00
      1.4 3.000E-08 3.000E+08 6. .2 .17 7.000E+09
NSIZE      0 0 0 8 8 8 0 0 0
YIELD =      1.030E+10 8.190E+11
MELT =      1.085E+10 1.000E+08 0.E0 9.975E-01 1.000E-01

PMMA-8K8 (BARKER) RHOS =      1.184E+C0 CFP = 000 DPY = 001
EQST =      7.000E+10 4.050E+11 1.000E+10 1.000E+00 2.500E-01 39640E+11
YIELD =      1.000E+06 1.950E+10 2.850E+09

HF-1      RHOS =      7.85E0 CFP= 000 DPY= 002 NCON= 0
EQST=      1.589E+12 5.170E+12 7.360E+10 1.69E0 0.25E0 5.170E+13
YIELD =      1.030E+10 8.190E+11
MELT =      1.085E+10 1.000E+08 0.E0 9.975E-01 1.000E-01

LEAD (KOHN) RHOS =      11.355 CFP = 000 DPY = 000
EQST =      5.008E+11 4.986E+11 9.155E+09 2.2 0.25 2.019E+12

SPEC Z12      NHNU =      95 (4(F10.5,F7.5,3X))
.03571 .00000 .10714 .00000 .17857 .00000 .25000 .00000
.32143 .00001 .39286 .00002 .46429 .00003 .53571 .00004
.60714 .00006 .67857 .00009 .75000 .00012 .82143 .00016
.89286 .00021 .96429 .00026 1.07143 .00093 1.21429 .00156
1.35714 .00209 1.50000 .00254 1.64286 .00290 1.78571 .00316
1.92857 .00333 2.08333 .00436 2.25000 .00508 2.41667 .00565
2.58333 .00608 2.75000 .00635 2.91667 .00648 3.12500 .00993
3.37500 .01053 3.62500 .01145 3.87500 .01269 4.12500 .01420
4.37500 .01563 4.62500 .01684 4.87500 .01782 5.16667 .02577
5.50000 .02789 5.83333 .02884 6.16667 .02976 6.50000 .03075
6.83333 .03069 7.16667 .03068 7.50000 .03062 7.83333 .02941
8.25000 .04213 8.75000 .03797 9.25000 .03188 9.75000 .02682
10.25000 .02138 10.75000 .01842 11.25000 .01734 11.75000 .01616
12.25000 .01546 12.75000 .01464 13.25000 .01379 13.75000 .01311
14.50000 .02460 15.50000 .02280 16.50000 .02070 17.50000 .01870
18.50000 .01720 19.50000 .01610 20.50000 .01530 21.50000 .01480
22.50000 .01450 23.50000 .01400 24.50000 .01160 25.50000 .00680
26.50000 .00440 27.50000 .00580 28.50000 .00720 29.50000 .00730
30.50000 .00680 31.50000 .00630 32.50000 .00590 33.50000 .00550
34.50000 .00510 35.50000 .00480 36.50000 .00440 37.50000 .00410
38.50000 .00370 39.50000 .00340 40.50000 .00320 41.50000 .00290
42.50000 .00270 43.50000 .00250 44.50000 .00230 45.50000 .00210
46.50000 .00200 47.50000 .00180 48.50000 .00170 49.50000 .00160
51.25000 .00284 53.75000 .00376 57.50000 .00490

```

7/8/79

FIGURE C.1 DATA BANK CONTAINING GENERAL RUNNING INFORMATION, MATERIAL PROPERTY DATA, AND A SPECTRUM (ON TAPE 4)

ABS DATA

*** ABSORPTION EDGE AND COEFFICIENT DATA BORROWED MAINLY FROM THE FSCATT ***
 *** CODE OF S.S.S. THE DATA ARE FROM THE LLL COMPILATION OF X-RAY CROSS ***
 *** SECTIONS, BY W. H. MCMASTERS, ET.AL., SECT.2, REV. 1, MAY, 1959 ***
 *
 *** VALUE OF COEFFICIENTS USED IN FIT OF CROSS SECTION DATA EQUATION - ***
 *** $LN(SIGMA/SIGMA_0) = A(0, I) + A(1, I) * X + A(2, I) * X^2 + A(3, I) * X^3$ ***
 *** WHERE $X = LN(HNU)$ WITH HNU IN KEV, $SIGMA_0 = 1(BARN/ATOM)$, SUBSCRIPT -1- ***
 *** REFERS TO THE FIT PAST THE ITH EDGE. ***

HYDROGEN	X-RAY ABS NOE =	1 ATWT =	1.008	1 H
EDGE1	1.00000E 0			1 H
COEF1	2.44950E 0,-3.34932E 0,-4.72054E -2, 7.10529E -3			1 H
HELIUM	X-RAY ABS NOE =	1 ATWT	4.0026	2 HE
EDGE1	1.00000E 0			2 HE
COEF1	6.06498E 0,-3.29055E 0,-1.07282E -1, 1.44502E -2			2 HE
LITHIUM	X-RAY ABS NOE =	1 ATWT =	6.9390	3 LI
EDGE1	1.00000E 0			3 LI
COEF1	7.75366E 0,-2.81798E 0,-2.41741E -1, 2.62541E -2			3 LI
BERYLLIUM	X-RAY ABS NOE =	1 ATWT =	9.0120	4 BE
EDGE1	1.00000E 0			4 BE
COEF1	9.04503E 0,-2.83490E 0,-2.09990E -1, 2.29488E -2			4 BE
BORON	X-RAY ABS NOE =	1 ATWT =	10.81	5 B
EDGE1	1.00000E 0			5 B
COEF1	9.95057E 0,-2.74173E 0,-2.15138E -1, 2.27845E -2			5 B
TITANIUM	X-RAY ABS NOE =	2 ATWT =	47.90	22 TI
EDGE1	1.00000E 0, 4.96500E 0			22 TI
COEF1	1.31074E 1,-2.53681E 0,-9.37662E -2,-8.07696E -4			22 TI
COEF2	1.43509E 1,-1.66361E 0,-3.31403E -1, 2.61935E -2			22 TI
VANADIUM	X-RAY ABS NOE =	2 ATWT =	50.94	23 V
EDGE1	1.00000E 0, 5.46500E 0			23 V
COEF1	1.32515E 1,-2.49745E 0,-1.06643E -1, 7.70206E -5			23 V
COEF2	1.47598E 1,-1.88849E 0,-2.71904E -1, 2.15824E -2			23 V
CHROMIUM	X-RAY ABS NOE =	2 ATWT =	52.00	24 CR
EDGE1	1.00000E 0, 5.98900E 0			24 CR
COEF1	1.34235E 1,-2.51606E 0,-1.01138E -1,-2.36898E -4			24 CR
COEF2	1.48015E 1,-1.82384E 0,-2.79236E -1, 2.17419E -2			24 CR
MANGANESE	X-RAY ABS NOE =	2 ATWT =	54.94	25 MN
EDGE1	1.00000E 0, 6.54000E 0			25 MN
COEF1	1.35761E 1,-2.49626E 0,-1.07826E -1, 6.28831E -4			25 MN
COEF2	1.48969E 1,-1.79894E 0,-2.83640E -1, 2.22096E -2			25 MN
IRON	X-RAY ABS NOE =	2 ATWT =	55.85	26 FE
EDGE1	1.00000E 0, 7.11200E 0			26 FE
COEF1	1.36697E 1,-2.39272E 0,-1.36795E -1,-2.37212E -4			26 FE
COEF2	1.43458E 1,-1.23512E 0,-4.18728E -1, 3.21614E -2			26 FE
NICKEL	X-RAY ABS NOE =	3 ATWT =	58.71	28 NI
EDGE1	1.00000E 0, 1.01200E 0, 8.33300E 0			28 NI
COEF1	1.38363E 1,-2.47740E 0, .00000E 0, .00000E 0			28 NI
COEF2	1.39849E 1,-2.48097E 0,-8.88292E -2, 3.18989E -5			28 NI
COEF3	1.42375E 1,-9.66762E -1,-4.78299E -1, 3.66306E -2			28 NI
COPPER	X-RAY ABS NOE =	3 ATWT =	63.54	29 CU
EDGE1	1.00000E 0, 1.10000E 0, 8.97900E 0			29 CU
COEF1	1.40954E 1,-2.59039E 0, .00000E 0, .00000E 0			29 CU
COEF2	1.42443E 1,-2.58831E 0,-6.51996E -2,-4.13025E -4			29 CU
COEF3	1.45807E 1,-1.18359E 0,-4.13899E -1, 3.12129E -2			29 CU
ZINC	X-RAY ABS NOE =	5 ATWT =	65.37	30 ZN
EDGE1	1.00000E 0, 1.02100E 0, 1.04400E 0, 1.19600E 0			30 ZN
EDGE2	9.65900E 0			30 ZN
COEF1	1.20599E 0,-1.12290E 0, .00000E 0, .00000E 0			30 ZN
COEF2	1.38301E 1,-2.62547E 0, .00000E 0, .00000E 0			30 ZN
COEF3	1.41741E 1,-2.63124E 0, .00000E 0, .00000E 0			30 ZN
COEF4	1.43226E 1,-2.62555E 0,-2.50198E -2,-3.53392E -4			30 ZN
COEF5	1.44132E 1,-9.34286E -1,-4.77048E -1, 3.62589E -2			30 ZN

FIGURE C.2 DATA BANK CONTAINING X-RAY ABSORPTION DATA FOR SEVERAL ELEMENTS (ON TAPE 2)

dose profiles are all contained on Tape 4. Only x-ray absorption data are on Tape 2. The two banks are used so that GENRAT can read properties from Tape 4 and then be referred to Tape 2 to pick up absorption characteristics without losing its position in Tape 4.

The data banks in Figures C.1 and C.2 contain a series of separate data groups. Each group is constructed strictly in accordance with the requirements of GENRAT. However, the groups themselves may be in any order and may be spaced by blanks or comment cards to annotate the bank.

The data banks may be constructed by placing card images on a file before the PUFF calculation or by letting GENRAT write the file during the calculation as in the preceding examples. We have stored large data banks on an UPDATE file and written the data bank from UPDATE as a COMPILE file. Alternatively, the bank may be written by copying cards to the appropriate file using control cards.

The banks are used in the following way. The data deck is constructed in the normal way except that the information in the bank is omitted. Instead, some indicator is provided to show where the data should be found. Figure C.3 shows a data deck for an impact with a hot aluminum target. The "X" in the first column of the IDENT card shows that the remainder of the general running data should come from the data bank and that the NAMELIST routine EXTRA should be called. The letters "SHOCKEY" in columns 72-80 give the title of the set of general running data to be used. These letters correspond to those in column 12-20 following "HEADING" in Figure C.1. After GENRAT reads the general running information, it reads the "EXTRA" card and calls EXTRA to read the "\$NLIST..." line. The end-of-file (7/8/9) stops the reading in EXTRA. The "T" in the first column of the material cards for 1145 aluminum show that the properties for these materials must come from the data bank.

In GENRAT the input deck of Figure C.3 is used to construct a complete data deck. The GENRAT output for this case is in Figure C.4. The indicators to the right of the card images help to show the process. The variable IND is the indicator in the first column. IN is the file from which the line is taken: IN = 5 shows the standard input file,

whereas IN = 4 indicates Tape 4, the data bank. Hence in this case the first line is from the data deck. Next the data bank is searched (by the subroutine REDR) for a label HEADING SHOCKEY. Then GENRAT reads the next four lines from the data bank. Control then returns to the data bank and the subroutine EXTRA is called to read and print the NAMELIST data which reinitializes the flyer velocity to 1.46×10^4 cm/sec. Then GENRAT reads the line T1145-AL, which causes REDR to find the appropriate line in the data bank again. GENRAT repeats the reading of the material name card and then reads the remaining properties from the data bank. After the two sets of aluminum data, control returns to the data deck for reading the cell layout and the second NAMELIST record.

A second example of the use of data banks is shown in Figures C.5 and C.6. The data deck in Figure C.5(a) describes a radiation problem using a spectrum labeled SPEC_Z12, which deposits energy into three materials: asbestos phenolic (AP), fused silica, and quartz. The "T" in the first column indicates which data are taken from Tape 4. The material property data for AP are also shown as part of a data bank in Figure C.5(b). The completed input deck constructed by GENRAT and exhibited in Figure C.6 shows the source for each line in the column on the right labelled "IN". IN = 5 is the normal input file shown in Figure C.5(a); IN = 4 means Tape 4 and IN = 2 means Tape 2. The line headed "TAP" in the deck in Figure C.5(a) brings in the properties from Tape 4 shown in the data bank of Figure C.5(a). Included in these properties are the chemical constituent data needed for the x-ray absorption calculation and read in the subroutine DEPOS. The constituent data names the chemical species (e.g., IRON), the source of the absorption data (e.g., ITAPE = 2), and the weight fraction (PBW). The IRON is located by REDR on Tape 2, and DEPOS reads the number of edges (NOE), atomic weight (ATWT), the EDGES, and the COEFS (A_0 , A_1 , A_2 , and A_3 referred to in Appendix A). The same process is repeated for silica and quartz, except that PBW is interpreted as the number of atoms of the constituent in the molecule, instead of the weight fraction (because $PBW \geq 1.0$).

TIDENT AP EXPERIMENT H 3116 X-RAY DEPOSITION INTO A HEAT SHIELD APDS

TAP (ERLICH)

TFUSED SILICA-BARKER

TQUARTZ (GRAHAM)

NLAYER = 3 JMAT = 1 2 3
 NZONES= 1 103 CELLS IN 3.550E-01 CM DX = 1.000E-04 RATIO = 1.05E0
 NZONES= 1 13 CELLS IN 6.350E-01 CM
 NZONES= 1 16 CELLS IN 8.000E-01 CM
 NSPEC = 1 ANGLE = 0.
 TSPEC Z12 NHNU = 0 ECAL = 1.100E+02 START = 0. SSTOP = 5.000E-09
 7/8/9

(a) SAMPLE DATA DECK FOR RADIATION PROBLEM

AP (ERLICH) RHOS = 1.843 CFP = 001 DPY = 001 NCON = 6
 EQST = 3.800E+11-3.800E+11 8.200E+09 0.05 0.02 3.800E+11
 RHO = 1.45
 AK = 1.030E+10 MUP = 0.
 NREG = 2
 RHOP = 1.45 1.703 2.55 2.55 2.55 2.6
 COSQ = 4.0 4.0 4.0 4.0 4.0 4.0
 C1 = 0.3 0.3 0.3 0.3 0.3 0.3
 P1 = 0.
 1 P2 = 3.000E+09 DELP = -4.000E+08
 2 P2 = 3.500E+10 DELP = -2.700E+09
 EMELT = 4.000E+09 3.000E+09 0.15 0.25 -0.06
 IRON ITAPE= 2 PBW = 0.0061
 OXYGEN ITAPE= 2 PBW = 0.387
 NICKEL ITAPE= 2 PBW = 0.0017
 SILICON ITAPE= 2 PBW = 0.1052
 MAGNESIUM ITAPE= 2 PBW = 0.19
 CARBON ITAPE= 2 PBW = 0.31

(b) SAMPLE PROPERTY DATA FOR AP IN DATA BANK ON TAPE 4

FIGURE C.5 DATA DECK AND DATA BANK, ILLUSTRATING USE OF DATA BANKS FOR RADIATION PROBLEMS WITH MULTICONSTITUENT MATERIALS


```

SILICON  X-RAY ARS NDE = 1.83900E+00 2 ATWT = 28.090
EDGE 1.00000E+00 1.83900E+00 1.26919E-01 0.
CDEF5 1.12236E+01 -2.73639E+00 1.26919E-01 2.74002E-02
OXYGEN 1.32678E+01 -1.98148E+00 -3.17030E-01 2.74002E-02
OXYGEN 11APE= 2 PHW= 2.0000000 1 ATWT 15.999
EDGE 1.00000E+00
OXYGEN 1.17128E+01 -2.57213E+00 -2.05923E-01 1.99266E-02
CDEF5 DEPOS - CONST. DENSITIES (G/CM3), RHUC = 1.029E+00 1.172E+00

QUARTZ (GRAHAM)
QUARTZ (GRAHAM) PHOS= 2.450E+00 CFP = 000 UPY = 000
EDGE 8.695E+11 -8.695E+11 8.695E+10 6.200E-01 2.500E-01 8.695E+11 -0.
SILICON 11APE= 2 PHW= 1.0000000 2 ATWT = 28.090
SILICON 1.00000E+00 1.83900E+00 1.26919E-01 0.
EDGE 1.12236E+01 -2.73639E+00 -3.17030E-01 2.74002E-02
CDEF5 1.32678E+01 -1.98148E+00 -3.17030E-01 2.74002E-02
OXYGEN 11APE= 2 PHW= 2.0000000 1 ATWT 15.999
OXYGEN 1.00000E+00
OXYGEN 1.17128E+01 -2.57213E+00 -2.05923E-01 1.99266E-02
CDEF5 DEPOS - CONST. DENSITIES (G/CM3), RHUC = 1.239E+00 1.411E+00

NLAYER = 3 JMAT = 1 2 3 -0 -0 -0 -0 -0 -0 INO= 1 IN= 5
NZONES= 1 103 CELLS IN 3.550E-01 CM OX = 1.000E-04 HATID = 1.050E+00 INO= 1 IN= 5 CM, CM,
NZONES= 1 13 CELLS IN 6.350E-01 CM -0. INO= 1 IN= 5 CM, CM,
NZONES= 1 14 CELLS IN 8.000E-01 CM -0. INO= 1 IN= 5 CM, CM,
NSPEC = 1 1 ANGLE = 0.110E+03 START = 0.55TOP = -5.00E-08 INO= 1 IN= 5 DEPOS-
SPEC 05 NNU = 0 FCAL = 0.110E+03 START = 0.55TOP = -5.00E-08 INO= 1 IN= 5 DEPOS-
SPEC 05 NNU = 0.1714E+00 0.1714E+00 0.1714E+00 0.1714E+00 0.1714E+00 0.1714E+00 0.1714E+00 0.1714E+00
0.35710.00000 0.35710.00000 0.35710.00000 0.35710.00000 0.35710.00000 0.35710.00000 0.35710.00000 0.35710.00000
0.32143.00001 0.32143.00001 0.32143.00001 0.32143.00001 0.32143.00001 0.32143.00001 0.32143.00001 0.32143.00001
0.6714.00006 0.6714.00006 0.6714.00006 0.6714.00006 0.6714.00006 0.6714.00006 0.6714.00006 0.6714.00006
0.89286.00021 0.89286.00021 0.89286.00021 0.89286.00021 0.89286.00021 0.89286.00021 0.89286.00021 0.89286.00021
1.35714.00209 1.35714.00209 1.35714.00209 1.35714.00209 1.35714.00209 1.35714.00209 1.35714.00209 1.35714.00209
1.92857.00333 1.92857.00333 1.92857.00333 1.92857.00333 1.92857.00333 1.92857.00333 1.92857.00333 1.92857.00333
2.58333.00608 2.58333.00608 2.58333.00608 2.58333.00608 2.58333.00608 2.58333.00608 2.58333.00608 2.58333.00608
3.37500.01053 3.37500.01053 3.37500.01053 3.37500.01053 3.37500.01053 3.37500.01053 3.37500.01053 3.37500.01053
4.37500.01563 4.37500.01563 4.37500.01563 4.37500.01563 4.37500.01563 4.37500.01563 4.37500.01563 4.37500.01563
5.50000.02789 5.50000.02789 5.50000.02789 5.50000.02789 5.50000.02789 5.50000.02789 5.50000.02789 5.50000.02789
6.83333.03069 6.83333.03069 6.83333.03069 6.83333.03069 6.83333.03069 6.83333.03069 6.83333.03069 6.83333.03069
8.25000.04213 8.25000.04213 8.25000.04213 8.25000.04213 8.25000.04213 8.25000.04213 8.25000.04213 8.25000.04213
10.25000.02134 10.25000.02134 10.25000.02134 10.25000.02134 10.25000.02134 10.25000.02134 10.25000.02134 10.25000.02134
12.25000.01546 12.25000.01546 12.25000.01546 12.25000.01546 12.25000.01546 12.25000.01546 12.25000.01546 12.25000.01546
14.50000.02440 14.50000.02440 14.50000.02440 14.50000.02440 14.50000.02440 14.50000.02440 14.50000.02440 14.50000.02440
18.50000.01720 18.50000.01720 18.50000.01720 18.50000.01720 18.50000.01720 18.50000.01720 18.50000.01720 18.50000.01720
22.50000.01450 22.50000.01450 22.50000.01450 22.50000.01450 22.50000.01450 22.50000.01450 22.50000.01450 22.50000.01450
26.50000.00440 26.50000.00440 26.50000.00440 26.50000.00440 26.50000.00440 26.50000.00440 26.50000.00440 26.50000.00440
30.50000.00680 30.50000.00680 30.50000.00680 30.50000.00680 30.50000.00680 30.50000.00680 30.50000.00680 30.50000.00680
34.50000.00510 34.50000.00510 34.50000.00510 34.50000.00510 34.50000.00510 34.50000.00510 34.50000.00510 34.50000.00510
38.50000.00370 38.50000.00370 38.50000.00370 38.50000.00370 38.50000.00370 38.50000.00370 38.50000.00370 38.50000.00370
42.50000.00270 42.50000.00270 42.50000.00270 42.50000.00270 42.50000.00270 42.50000.00270 42.50000.00270 42.50000.00270
46.50000.00200 46.50000.00200 46.50000.00200 46.50000.00200 46.50000.00200 46.50000.00200 46.50000.00200 46.50000.00200
51.25000.00284 51.25000.00284 51.25000.00284 51.25000.00284 51.25000.00284 51.25000.00284 51.25000.00284 51.25000.00284
DEPOS - ESIM = 1.100E+02 CAL/CM2

```

FIGURE C.6 INPUT CONSTRUCTED BY GENRAT FOR RADIATION PROBLEM IN WHICH GENERAL RUNNING INFORMATION, MATERIAL PROPERTIES, RADIATION ABSORPTION DATA, AND SPECTRUM ARE ON DATA BANKS (Concluded)

Additional Input: EXTRA and H-DATA

Occasionally it is necessary to insert additional information for which there is no standard reading procedure. In that case the EXTRA routine is called to read the information through a NAMelist READ statement, or HDATA is called to read variables into the H array. The use of EXTRA is considered first.

In the special NAMelist READ statement in EXTRA, the variable and its value are given. The sample shown at the end of Figure C.4 is `$NLIST EHL(12) = 20*4.46E9, RHOS(2) = 2.784$`. The dollar sign in column 2 and at the end delimit the information and also signal a NAMelist READ. The list of variables used in EXTRA is called NLIST: it includes most of the material properties, the main cell arrays, indicators, and other variables for which a change might be required. The effect of the READ statement mentioned above is to initialize 20 values of EHL, the internal energy, beginning at EHL(12) with a value of 4.46×10^9 and then reset the initial density, RHOS, of the second material to 2.784. This case illustrates two uses of EXTRA: the EHL array is being initialized to represent a preheating of the target, and RHOS is being reset. RHOS was initialized to 2.705 in the normal way with the material property data. That value is appropriate for preheated and expanded aluminum and is needed for giving the cells the correct initial mass and density. However, for the equation-of-state calculations, the standard density of 2.784 is required; this resetting is accomplished after the layout by means of the EXTRA routine as shown.

Pressure boundary information may be inserted through the NAMelist READ as shown in Figure C.5. The parameters P6 and T6 define a pressure history with the form

$$P = P6 \exp (t/T6)$$

Subscripts (1) for P6 and T6 indicate the first boundary, whereas (2) indicates the final boundary.

CALLS to EXTRA may occur at two points in GENRAT: immediately following the general running information and at the end of the deck. As mentioned above, the first of these CALLS is triggered by an "X" in the first column of the IDENT line. The second CALL is caused by a line with the letters "_EXTRA" preceding the lines containing the NAMELIST data.

The NAMELIST statement does not permit the use of alpha or octal data. Therefore, to initialize the H parameter array, it was necessary to construct a special reading subroutine, HDATA. HDATA is called only at the end of the data deck. If both EXTRA and HDATA are used, HDATA must precede. The data line for HDATA is preceded by a line containing the label "_H-DATA". HDATA reads only 1 or 2 H values for each call, but multiple calls are possible by providing additional "_H-DATA" and data lines. The data are in a single line containing, J, I, and K for the equation $H(J,I) = K$, and K is read in an R5 format. In our work the only H values reset with HDATA have been at first or last coordinates to change boundary conditions; therefore, not more than two values were required.

Input Description for Historical Prints

Historical listings can be obtained for any variable in the cell or coordinate arrays and for several other variables. This section describes the input data required to obtain the histories, and the subroutines used.

Input Directives. Each input directive for a historical listing consists of two groups of symbols: one part is for the type of data and one part is for the location in the material. The directives are provided in free-field format in columns 11 to 80 of a data line. Samples of these directives are

S1,26 D,18 COM1, 3.25

In each of these three pairs, the characters before the comma are a directive group that designates a data type: S1 is thermodynamic stress in the direction of propagation, D is density, and COM1 is the first variable assigned to the COM array, a large array available for use with constitutive relations that require extra storage. All these type

designators are defined in Table C.1. The number after the comma are a directive group that designates a location within the material. For example, 26 and 18 are cell numbers. The decimal 3.25 means layer 3, 25% of the distance from the front of the layer. The groups of characters forming a directive group are separated by either commas or blanks.

More samples of the directives are given in Table C.2. The first 10 spaces of each line may be used to identify the line or may be left blank. The next 70 characters contain the designators that are processed to determine which stress histories are required. Table C.2 shows several sets of directive groups. Each set begins with one or more type designator groups (beginning with a letter) and ends with one or more numerical groups. A set constitutes a request for histories of all the types given by type designators at each of the locations in the numerical groups.

The first line of the table contains five numbers that constitute a set requesting stress histories in the direction of propagation at those cell locations. In this case a type designator was omitted: S1 is assumed to be the type if the first character on the first line is an integer. The next type designator is D for density, followed by three cell locations for which density histories are required. On the second line is a large set containing five type designators: S1, S2, S3, E, and Y. Hence first, second, and third principal stresses, internal energy, and yield strength are requested at cells 6, 7, and 8. Next the coordinate position X is requested at coordinate points 6 and 9. The third line shows a request similar to that on the second line, except that the second request set (C, U, SD1, 24, 30, 35) is continued on the fourth line. The fourth line also contains a set requesting histories of the 24th variable in the COM array for cells 5, 10, 15, and 20.

In addition to the requested histories is a group of histories that are automatically obtained. The time increment (DTNH), the calculation time for each time step (DELTIM), and the cell controlling the time step (JTS) are always given. In a multilayer problem, interface stress

Table C.1

DEFINITIONS OF DIRECTIVE GROUPS

C	Sound speed, cm/sec
COM, COM2, COM12	An array containing special variables used by constitutive relations that require more than the standard arrays. A number immediately following COM indicates the particular one of these special variables requested.
D	Density, g/cm^3
DPDD	$\partial P / \partial \rho$, $\text{dyn/cm}^2 / (\text{g/cm}^3)$
DPDE	$\partial P / \partial E$, $\text{dyn/cm}^2 / (\text{erg/g})$
E	Internal energy, erg/g
H1	H(J,1), cell state indicator
H2	H(J,2), cell or coordinate type indicator
H3	H(J,3), cell state indicator
IMP	Impulse = $\int R dt$, dyn-sec/cm^2
NEM, NET	Special arrays; meaning depends on the material model
P	Pressure, dyn/cm^2
R	Mechanical stress in direction of propagation, dyn/cm^2
SDT	Deviator stress in the circumferential direction in cylindrical problems, dyn/cm^2
SD1, SD2, SD3	Deviator stresses in the direction of propagation, and in two orthogonal directions. For cylindrical geometry, the second ₂ direction is circumferential and the third is axial, dyn/cm^2
S1, S2, S3	Principal stress in the direction of propagation and in two orthogonal directions. For cylindrical geometry, the second direction is circumferential and the third is axial, dyn/cm^2
S-INT	Interface stress--average ₂ of stresses in cells on either side of interface, dyn/cm^2

Table C.1 (concluded)

T	Spall strength, dyn/cm^2
U	Coordinate velocity, cm/sec
V	Specific volume, cm^3/g
X	Coordinate location, cm
X0	Initial coordinate location, cm
Y	Yield strength, dyn/cm^2
Z	Cell mass, g/cm^2 , g/cm , or g for planar, cylindrical and spherical geometries, respectively
1,2, any integer	Cell or coordinate number
3.25	Location designator. Integer before the decimal indicates the layer number (not counting void layers). The following number, including the decimal, is the fractional distance into the layer

Table C.2

SAMPLE INPUT DIRECTIVES

1*	10	11					80
JEDIT =	16	23	4	29	18	D,8,9,11	
JEDIT 2	S1,S2,S3,E,Y,			6,7,8		X,6, 9	
HIST 3	U, H2,NEM,16			C,U,	SD1	24	
4th CARD	30,35,COM24			5	10	15	20

* Column numbers on an input card; first column should be left blank.

histories are listed between each layer. With the current dimensions, a total of 100 histories may be printed.

Subroutine Description. Three subroutines, PRESCR, STORR and SCRIBE, process the input directives, store the required cell information during the wave propagation calculation, and print the histories at the end of the calculation. Here only an outline of the procedure is given.

During the initialization stage of a computation, the input directives are read by GENRAT. At the end of GENRAT, PRESCR (meaning PRE-SCRIBE) is called. PRESCR examines the input directives character by character and constructs three arrays: JTYP, JEDIT, and JNUM. JTYP contains the title of the history, including the data type and cell location. JEDIT is the j value of the cell, and JNUM is the location of the specific variable in the coordinate arrays.

At each time step during a wave propagation calculation, STORR is called to store all the requested variable values from that time step. The JNUM and JEDIT arrays are used to select the correct values for storage. Temporarily these values are stored in the A array. When part of the A array is filled, the values are buffered out to a disk file (called Tape 3) while the second part of the array is being filled. When the second part is full, storage begins again in the first part and the second part is buffered out. This process is repeated throughout the calculation.

At the end of the wave propagation calculation, STORR is called to complete buffering of information to the disk file. Then SCRIBE is called to print the histories. SCRIBE reads the disk file and prints 10 histories at a time. When one set of histories is complete, SCRIBE rewinds and rereads the file and prints another set until all the histories have been listed.

Additional Variables for Material Models: COM, LVAR, NVAR

An array of additional variables is provided for use with material models requiring more variables per cell than normally available. These extra variables are in the COM array. This section describes the use of the array, when it is needed, how to use it when adding new material models, and how to obtain historical listings of values in the array.

The usual variables available at each cell for each material model are those in the COMMON labeled COORD. Included are the yield array YHL, the quantities NEM and NET, and an indicator H(J,I). For material models where these variables are insufficient, the COM array is provided. So far, the following subroutines have required this extra storage: BFRACT2 (11 variables), BFRACT3 (20), HYPO (3), PEST (5), REBAR (7), and SHEAR2 (indefinite number). The number required for SHEAR2 is $4 + \text{NANG} + 2 \sum_i \text{NSIZE}_i$, where NANG and NSIZE_i are input data for SHEAR2.

Locations within COM are assigned with the aid of a second array LVAR(J). LVAR(J) is the location in COM at which the storage for the jth cell begins. Then, for example, the fifth value in COM for the jth cell is COM(L+4) where $L = \text{LVAR}(J)$. NVAR(M) (an input quantity) is the number of additional variables assigned to each cell. The location quantities LVAR may be assigned during the initialization of the problem or during the running. For the fracture routines BFRACT2 and BFRACT3, the assignment is made for the jth cell during the computation at the time fracture begins at that cell. Hence, if the cell never undergoes fracture, it does not require the added storage.

The COM array is especially convenient for providing variables to new models because the formal parameters of the model subroutine may be either scalars or arrays. For example, BFRACT2 has the formal parameters FU2D, CL, and CN, where FU2D is a scalar and CL and CN are each arrays of five quantities. In the CALL statement these same parameters are listed as COM(L), COM(L+1), and COM(L+6).

Historical listings can be obtained of all array quantities, including COM array quantities. The form of the request for the listing is "COM2 or "COM11". In the sample of the preceding paragraph, COM2 would indicate the second value in the COM array for the particular cell, and that corresponds to CL(1) in the CALL to BFRAC2. Similarly, COM11 refers to CN(5). Usually the CALL statements in HSTRESS must be compared with the formal parameters of the material model to relate the COM quantities to the variables of interest.

Sample Data Decks

A number of sample data decks are provided to illustrate the main features of PUFF and the range of problems that can be treated. General guide lines for constructing the decks are listed below.

- The data fields are usually in multiples of 5 or 10 characters.
- The first column is reserved for indicators.
- Columns 2 through 10 are usually labels only.
- Any number of decks can be run, one following the next with only an end-of-file (7/8/9) between decks.

These features are illustrated in the following sample decks.

The data decks are grouped according to problem type, but each also illustrates many other features. Figures C.7 through C.10 (and Figure C.3) show impacts in planar geometry, Figures C.11 through C.13 are for cylindrical geometry, and Figure C.14 is for spherical geometry. Explosives are featured in Figures C.15 and C.16 and radiation in Figures C.17 through C.20 (and Figure C.5). A pressure boundary provides the loadings in Figures C.21 and C.22.

The JEDITS are listed in several ways. Many are integers without TYPE designation, indicating that only σ_1 is required. In Figure C.11, all three principal stresses and COM(3) are required at positions given by decimals such as 2.1 (2.1 means a location in layer 2, 0.1 times the thickness through the layer).

```

IDENT 847 I FRACTURE IN 1145 AL, FRACTURE IMPACT EXPERIMENT AT 423 FT/SEC
NED1T = 0 NJED1T = 2
JED1TS = 27 28 29 30 31 32 15 16 17 18 19 20 21 22
          23 24 25 26
NED1T = 20 JCYCS = 180 CKS = 3.0 TS = 3.000E-06
NMTRLS = 2 MATFL = 1 UZERO = 1.289E+04
AL 1145 RHOS = 2.7E0 CFP = 000 DPY = 003 NCON = 0
EQST = 7.600E+11 1.500E+12 1.220E+11 2.04E0 0.25E0 0.
TENS = -1.000E+11 0. -1.E0
VISC = 4.E0 0.05E0 0.
YIELD = 2.000E+09 3.000E+11 0.
AL 1145 FR RHOS = 2.7E0 CFP = 010 DPY = 003 NCON = 0
EQST = 7.600E+11 1.500E+12 1.220E+11 2.04E0 0.25E0 0.
DFR1 1145-0.01 -4.000E+09 1.000E-04 3.000E+09-3.000E 09-4.000E+08
TENS = -1.200E+10 0.
VISC = 4.E0 0.05E0 0.
YIELD = 2.000E+09 3.000E+11 0.
NLAYER= 2 JMAT = 1 2
NZONES= 1 10 CELLS 1N 0.236 CM
NZONES= 1 25 CELLS 1N 0.635 CM
7/8/9

```

FIGURE C.7 INPUT DECK FOR IMPACT IN 1145 ALUMINUM, ILLUSTRATING DUCTILE FRACTURE DATA AND JEDITS WITH NO TYPE INDICATOR

```

IDENT = S25 E SHOT 8678-1-S25 IN ARMCO IRON
C STANDARD IMPACT SIMULATION USED TO CALIBRATE OR CHECK BRITTLE FRACTURE
C MODELS
NTEDT = 0 NJED1T= 2 NREZON= 0
JED1T = 27 28 29 30 31 32 33 34 38 39 16 18 20 22
        23 24 25 26
NEDIT = 10 JCYCS = 150 CKS = 3.0 TS = 1.000E-05
NMTRLS = 2 MATFL = 1 UZERO = 1.960E+04
ARMCO IRON RHOS = 7.85 CFP = 020 DPY = 001
EQST = 1.589E+12 5.170E+12 7.360E+10 1.690E+00 2.500E-01 5.170E+13
TSR1 = -5.500E-04-1.000E+08 5.000E-05 4.000E+12-3.000E+09-5.270E+09
TSR2 = 0. 0. 2.500E-01 5.000E-01 4.000E-01 3.000E+00
YO = 2.000E+09 8.190E+11
PMMA-8KB (BARKER) RHOS = 1.184 CFP = 000 DPY = 001
EQST= 7.000E+10 4.050E+11 1.000E+10 1.000E+00 2.500E-01 3.640E+11
YIELD = 1.000E+06 1.950E+10 2.350E+09
NLAYER = 3 JMAT = 1 1 2
NZONES= 1 10 CELLS IN 1.133E-01 CM
NZONES= 1 25 CELLS IN 3.156E-01 CM
NZONES= 1 22 CELLS IN 4.800E-01 CM DX = 1.250E-02 RATIO = 1.05
7/8/9

```

FIGURE C.8 INPUT DECK FOR IMPACT IN ARMCO IRON, ILLUSTRATING BRITTLE FRACTURE AND A GEOMETRIC CELL LAYOUT

```

IDENT = 103A SYMMETRIC IMPACT OF TONALITE, COULOMB FRICTION AND POROSITY
NTEDT = 0 NJED1T = 1 0
JED1TS = 1 11 21 31 36 41
NED1T = 50 JCYCS = 200 CKS = 6.0 TS = 9.000E-06
NMTRLS = 1 MATFL = -1 UZERO = 6.320E+04
C C TONALITE RHOS = 2.58E0 CFP = C01 DPY = 002 NCON = C
EQST = 2.940E+11 3.056E+12 1.000E+12 2.E0 0.25E0 -6.406E+12
RHO = 2.56E0
AK = 2.000E+11 MUP = 1.000E+11 YC = 0.
NREG = 1 RHOP1 0.
RHOP = 2.56E0 2.762 E0 2.762E0 2.762E0 2.762E0 2.8E0
COSQ = 4.E0 4.E0 4.E0 4.E0 4.E0 4.E0
C1 = 0.2E0 0.2E0 0.2E0 0.2E0 0.5E0 0.5E0
P1 = 1.000E+08
IP2 = 3.300E+10 DELP = -3.500E+09 YADDP = 0.
TENS = -1.000E+11 -1.000E+11 -1.E0
YIELD = 0. 1.000E+11 0. 0.056E0
NLAYER = 1 JMAT = 1
NZONES= 3 10 CELLS IN 0.269 CM
20 CELLS IN 0.576 CM
10 CELLS IN 0.297 CM

```

7/8/9

FIGURE C.9 INPUT DECK FOR ASYMMETRIC IMPACT OF TONALITE, SHOWING COULOMB FRICTION WITH $\tan\phi = 0.056$, MULTIPLE ZONES IN LAYER, AND USE OF THE POREQST MODEL

```

IDENT PROJECTILE IMPACT ON CONCRETE AT 22.34M/SEC - TEST REBAR
NTEDT = 0 NJEDIT = 1
JEDIT = 5 8 11 14 16 18 20 22 25 27 29
NEDIT = 10 JCYCS = 150 CKS = 1.000E+02 TS = 1.000E-04
NMTRLS= 4 MATFL = 1 UZERO = 2.234E+03
IMPACTOR STEEL RHOS= 7.85E0 CFP= 000DPY= 001
EQST = 1.5889E12 5.170E12 7.360E10 1.69E0 0.25E0 5.170E13
YIELD= 1.222E10 8.188E11
REBAR STEEL RHOS= 7.85E0 CFP= 000DPY= 001
EQST = 1.5889E12 5.170E12 7.360E10 1.69E0 0.25E0 5.170E13
YIELD= 1.030E10 8.188E11
CONCRETE RHOS = 2.85 E0 CFP = 004 DPY = 000
EQST = 2.830E+11 0. 1.000E+11 2.000E+00 .25 0.
RHO = 2.22E0 AMU = 2.033E+11
AK = 7.000E+10 AK2 = -0.550E+02 MUP = 5.250E+10 MUP2 = 0.125E+03
MC = 1.040E+09-8.300E+08 2.703E+09 2.500E+08 1.E0
SCRIT(M)= 2.300E+08 DAMG = 0.100E-02
EVP = 0. -1.20E-02-3.500E-02-5.000E-02-2.230E-01
NREG = 4 NPRCAP = 0 P1 = -3.500E+08 W2 = 1.25E0
P2 = -1.000E+09 DELP = 0.
P2 = -2.400E+09 DELP = 0.
P2 = -3.400E+09 DELP = 0.
P2 = -1.533E+10 DELP = 0.
REBAR RHOS= 2.5015E0 CFP= 100DPY= 000 VAR= 7
FS= 0.05E0THET= 0.01MC= 31MS= 2
NLAYER = 6 JMAT = 1 3 4 3 4 3
NZONES= 1 14 CELLS IN 10.16E0 CM
NZONES= 1 1 CELLS IN 0.508E CM
NZONES= 1 1 CELLS IN 0.508E CM
NZONES= 1 6 CELLS IN 3.048E CM
NZONES= 1 1 CELLS IN 0.508E CM
NZONES= 1 1 CELLS IN 0.508E CM
7/8/9

```

FIGURE C.10 INPUT DECK FOR IMPACT OF A STEEL PLATE ONTO REINFORCED CONCRETE, SHOWING THE USE OF CAP AND REBAR SUBROUTINES AND MULTIPLE LAYERS OF A SINGLE MATERIAL

```

IDENT FR 5 FRAG ROUND OF ARMCO IRON TO SIMULATE CROWES TESTS 3 AND 4
C THE COMP B EXPLOSIVE IS TREATED BY A SIMULTANEOUS DETONATION
NTEOT = 0 NJEOT = 1 NREZON = 0 NALPHA = 2
JEOITS = S1.S2.S3.COM3 2.1. 2.2. 2.3. 2.4. 2.5. 2.6. 2.7. 2.8. 2.9
NEOIT = 10 JCYCS = 150 CKS = 3.000E+01 TS = 8.0005005
NMTRLS = 2 MATFL = 1 UZERO = 0.

COMPB RHOS = 1.72 CFP = 000 DPY = 012
EQST = 1. 0. 1. 1.841 1.841 0. 0.
QEXPL = 4.469E+10
TENS = -1.000E+09 0. -1.
MELT = -1.

ARMCO SH BAND RHOS = 7.85E0 CFP= 030 DPY= 002 NVAR = 58 NCON= 0
EQST= 1.589E+12 5.170E+12 7.360E+10 1.69E0 0.25E0 5.170E+13
SH2 3.000E+01 .2000E+00 1.100E-02 3.000E-04 0.17 0.070E+00 0.070E+00
1.4 3.000E-08 3.000E+08 6. .2 .17 7.000E+09
NSIZE 0 0 0 8 8 8 0 0 0
MELT = 1.085E+10 6.460E+09 1.500E-01 2.500E-01-6.000E-02
YIELD = 2.000E+09 8.190E+11

NLAYERS = 2 JMAT = 1 2
NZONES= 1 10 CELLS IN 1.5 INCH
NZONES= 1 10 CELLS IN 0.75 INCH
7/8/9

```

FIGURE C.11 INPUT DECK FOR THE CYLINDRICAL CALCULATION OF A FRAGMENTING ROUND, SHOWING DETONATION OF AN EXPLOSIVE, SHEAR BAND MODEL, AND ENGLISH UNITS IN THE LAYOUT

```

IDENT FR 4 FRAGMTG RND OF HF-1 TO SIMULATE CROWES TESTS 1 AND 2.
NTEOT = 0 NJEDIT = 3 NALPHA = 2
JEDIT = S1 2.1.2.2.2.3.2.4.2.5.2.6.2.7.2.8.2.9
JEDIT = COM2.COM3.COM4.12.13.14.15.16.17.18.19
JEDIT 3 S2.S3.U.0.17.18.19
NEDIT = 10 JCYCS = 300 CKS = 30. TS = 8.000E-05
NMTRLS = 2 MATFL = 1 UZERO = 0.

COMPB RHOS = 1.72 CFP = 000 DPY = 012
EQST = 1.0 0. 1.0 1.841 1.841
QEXPL = 4.469E+10
TENS = -1.000E+09 0. -1.
MELT = -1.

HF-1 RHOS = 7.85E0 CFP= 030 DPY= 002 NVAR = 58 NCON= 0
EQST= 1.589E+12 5.170E+12 7.360E+10 1.69E0 0.25E0 5.170E+13
SH 2 3.000E+01 .2E0 1.100E-02 1.000E-04 1.700E-01 7.000E-02 7.000E-02
1.4 3.000E-08 3.000E+08 6. .2 .17 7.000E+09
NSIZE 0 0 0 8 8 0 0 0
YIELD = 1.030E+10 8.190E+11
MELT = 1.085E+10 1.000E+08 1.500E-01 2.500E-01-6.000E-02
NLAYERS = 2 JMAT = 1 2
NZONES= 1 10 CELLS IN 1.5E0 INCH
NZONES= 1 10 CELLS IN 8.750E-01 INCH
7/8/9

```

FIGURE C.12 INPUT DECK FOR THE CYLINDRICAL CALCULATION OF A FRAGMENTING ROUND OF HF1 STEEL, SHOWING DETONATION OF AN EXPLOSIVE

```

CYLINDRICAL PUFF CALC OF CONCRETE/GROUT FOR KEOUGH ON 6172-10
NTEDT = 0 NJEDT = 1 NREZUN = 0 NALPHA = 2
JED1T = S1.1.1.5.1.75.2.1.2.2.2.3.2.4.2.5.2.6.2.8 S-1NT.0
NED1T = 10 JCYCS = 100 CKS = 100. TS = 4.000E-04
NMTRLS = 2 MATFL = -2 UZERU = 0.

CONCRETE
EQST = 2.830E+11 0. 1.000E+11 2. 0.25 0.
RHO = 2.22
AK = 7.000E+10 MUP = 5.250E+10 Y0 = 2.420E+08
NREG = 4
RHOP = 2.22 2.247 2.299 2.334 2.775 2.8
P1 = 3.500E+08
P2 = 1.000E+09 DELP = 0. YADD = 2.970E+08
P2 = 2.400E+09 DELP = 0. YADD = 2.680E+08
P2 = 3.400E+09 DELP = 0. YADD = 1.220E+08
P2 = 1.533E+10 DELP = 0. YADD = 2.690E+08
YIELD = 0. 5.250E+10 0. 0.

GROUT (DSRM-2)
EQST = 8.839E+10 0. 2.000E+11 2. 0.25 0.
RHO = 2.0668
AK = 8.035E+10 MUP = 3.887E+10 Y0 = 1.000E+08
NREG = 3
RHOP = 2.0668 2.142 2.245 2.353 2.353 2.4
P1 = 1.000E+08
P2 = 3.000E+08 DELP = -2.000E+07
P2 = 1.200E+09 DELP = -1.200E+08
P2 = 4.000E+09 DELP = -2.400E+08
YIELD = 1.000E+08 3.887E+10

NLAYERS= 3 JMAT = 0 1 2
NZONES= 1 0 CELLS IN 45. CM
NZONES= 1 5 CELLS IN 10. CM
NZONES= 1 25 CELLS IN 50. CM
7/8/9
FUNCTION SIGMAT(LS,T)
  DIMENSION PS(10),TS(10)
  DATA PS/0.,4.E9,4.E9,7*0./
  DATA TS/0.,6.E-5,5.0E-4,1.E-3,6*0./
  DATA NM/4/
  N=1
  SIGMAT=0.
20 N=N+1
  IF (N.GT. NM) RETURN
  IF (T.GT. TS(N)) GO TO 20
  SIGMAT=PS(N-1)+(PS(N)-PS(N-1))/(TS(N)-TS(N-1))*(T-TS(N-1))
  RETURN
END

```

FIGURE C.13 SIGMAT AND INPUT DECK FOR A CYLINDRICAL CALCULATION, ILLUSTRATING A HOLLOW OR EMPTY FIRST LAYER, PRESSURE BOUNDARY, AND USE OF POREQST

```

IDENT = SPHERICAL PUFF*/AL6061T6/PETN/PMMA/GROUT(SRIRMG-2C3) - CAP
C   A SPHERICAL EXPLOSION WITH A CENTAL BALL OF AL, THEN A SHELL OF PETN
C   IN A PLASTIC CONTAINER IN A LARGE SPHERE OF ROCK-MATCHING GROUT
NTEDIT =      0 NJEDIT =      1 NREZONE =      0 NALPHA =      3
JEDIT =      7   9  11  13  15  17  19  21  23  25
NEDIT =      10 JCYCS =      120 CKS =      1.000E+02 TS =      1.000E-04
NMTRLS =      4 MATFL =      -3 UZERO =      0.

AL6061-T6      RHOS =      2.707E0 CFP = 000 DPY = 001      NCJN = 1
EQST =      6.670E+11 1.000E+12 1.220E+11 2.040E0 2.500E-01 0.      0.
YIELD =      3.210E+09 2.670E+11 3.790E+10 0.      0.      0.      0.

PETN =      RHOS =      1.E0 CFP = 000 DPY = 063
EQST =      1.E0      0.      1.E0      1.45E0 1.45E0 0.      0.
IMAX =      21
RHOP =      1.E0      0.501E+11 0.794E0 0.300E+11 0.633E0 0.183E+11
      0.5E0      0.114E+11 0.398E0 0.725E+10 0.316E0 0.469E+10
      0.251E0 0.309E+10 0.2E0 0.207E+10 0.159E0 0.140E+10
      0.126E0 0.967E+09 0.1E0 0.675E+09 0.794E-01 0.477E+09
      0.633E-01 0.341E+09 0.500E-01 0.245E+09 0.398E-01 0.182E+09
      0.316E-01 0.130E+09 0.251E-01 0.960E+08 0.200E-01 0.711E+08
      0.156E-01 0.530E+08 0.126E-01 0.397E+08 0.100E-01 0.299E+08
TENS =      -1.000E+09 0.      -1.000E+09 0.      0.      0.      0.
MELT =      -1.000E0 0.      0.      0.      0.      0.      0.
VISC =      4.E0      2.500E-01 2.500E-01 0.      0.      0.      0.

PMMA-BKH (HARKER) RHOS =      1.184E0 CFP = 000 DPY = 001
EQST =      7.000E+10 4.050E+11 1.000E+10 1.000E0 2.500E-01 3.640E+11 0.
YIELD =      1.000E+06 1.950E+10 2.850E+09 0.      0.      0.      0.

SRIRMG-2C3 GROUT RHOS =      2.148E0 CFP = 004 DPY = 002
EQST =      1.450E+11 0.      1.000E+11 2.E0 2.500E-01 0.      0.
RHO =      2.1E0 AMU =      9.000E+10
AK =      1.046E+11 AK2 =      0.      MUP =      6.897E+10 MUP2 =      0.
MC =      2.600E+08-1.000E+08 1.321E+09 1.000E+09 2.E0
SCRIT =      2.300E+08 DAMAG =      1.000E-03
EVP =      0.E0      -4.531E-03-6.806E-03-1.257E-02
NREG =      3 NPRCAP =      0 P1 =      -1.000E+08 W2 =      1.000E+04
1P2 =      -3.200E+09 DELP =      -3.000E+07
2P2 =      -1.150E+09 DELP =      +.2000E+09
3P2 =      -4.000E+09 DELP =      +.1300E+09
YIELD =      4.345E+08 9.000E+10 0.      0.      0.      0.      0.
VISC =      4.E0      2.500E-01 2.500E-01 0.      0.      0.      0.

NLAYERS =      4 JMAT =      1 2 3 4
NZONES= 1      1 CELLS IN 9.068E-02 CM
NZONES= 1      5 CELLS IN 4.021E-01 CM
NZONES= 1      3 CELLS IN 1.422E-01 CM
NZONES= 1      36 CELLS IN 1.461E+01 CM DX =      1.000E-01 RATIO =      1.100E0

EXTRA
$NLIST RHL(9)=40*6.89E7,PHL(9)=40*6.89E7,SHL(9)=40*6.89E7,P6(1)=6.89E7,
T6(1)=1.0$
7/8/9

```

FIGURE C.14 INPUT DECK FOR SPHERICAL EXPLOSION OF PETN IN ROCK MATCHING GROUT, SHOWING USE OF A TABULAR EQUATION OF STATE, CAP MODEL, AND A NAMELIST STATEMENT

```

IDENT = 254 H EXPLOSIVE, FLYER, AND TARGET. SIMULTANEOUS DETONATION
C ELIMINATE C, D, AND S FROM EOS FOR EXPL. LET GAMMA BE CONSTANT.
C ADD 2 CM TO TARGET. CHECK WHETHER RIGHT IMPULSE IS OBTAINED (27.3 KBAR)
NTEDT = 0 NJEDIT = 2 C
JEDITS = 11 12 14 15 20 24 28 32 36 40 44 48 52 56
        60 64 68 72
NEDIT = 10 JCYCS = 170 CKS = 10.0 TS = 2.500E-05
NMTRLS = 3 MATFL = 1 UZERO = 0.
EL-576D RHOS = 1.4 CFP = 000 DPY = 002
EQST = 1.0 0. 1. 2. 2. 0.
TENS = -1. 0. -1.000E+11
MELT = -1. 0. 0. 0. 0.

AL6061-T6 RHOS = 2.707E0 CFP = 000 DPY = 002 NCON = 0
EQST = 6.670E+11 1.000E+12 1.220E+11 2.04E0 0.25E0 0.
TENS = -1.000E+11 0. -5.000E+08
YIELD = 3.210E+09 2.670E+11 3.790E+10

OTWR RHOS = 1.63E0 CFP = 000 DPY = 001 NCON = 0
EQST = 7.490E+10 1.500E+11 1.600E+10 0.74E0 0.25E0 1.310E+11
YIELD = 2.400E+08 3.000E+10 0.

NLAYER = 4 JMAT = 1 2 0 3
NZONES= 1 10 CELLS IN 0.202 CM
NZONES= 1 2 CELLS IN 0.0406 CM
NZONES= 1 0 CELLS IN 1.3700 CM
NZONES= 2 37 CELLS IN 1.0 CM, DX = 1.000E-02 RATIO = 1.05
        25 CELLS IN 3.0 CM, DX = 6.100E-02 RATIO = 1.05

EXTRA
$NLIST EHL(1)=10*3.64E+10 $
7/8/9

```

FIGURE C.15 INPUT DECK FOR EXPLOSIVELY THROWN FLYER PLATE IMPACTING OTWR AND ILLUSTRATING THE USE OF EXPLOSIVE, NAMELIST, COMMENTS, AND GAPS IN THE LAYERS

```

IDENT = 310 I RUNNING DETONATION
C   TREAT A RUNNING DETONATION THROUGH HMX, CDMF B, AND TNT TO STUDY THE
C   EFFECT OF OVERDRIVING OF A LOW C-J EXPLOSIVE BY A HIGH C-J EXPLOSIVE.
NTEDT =      0 NJEDIT =      2
JEDITS=      1   16   31   46   61   77   80   84   93  102  105  109  118  127
      130  134  137  140
NEDIT =      10 JCYCS =      200 CKS =      30.0      TS =      1.000E-04
NMTRLS =      4 MATFL =      1 UZERO =      0.

HMX      RHDS =      1.84      CFP = 000 DPY = 012
EQST =      1.0      0.      1.0      1.89      1.89      0.
QEXPL =      5.690E+10 0.0625      2.0
TENS =      -1.0      0.      -1.000E+11
MELT =      -1.0      0.      0.      0.      0.

COMP B    RHDS =      1.68E0      CFP = 000 DPY = 012      NCDN = 0
EQST =      1.E0      0.      1.E0      1.63E0      1.63E0      0.
QEXPL =      5.190E+10 0.0625E0      2.E0
TENS =      -1.E0      0.      -1.000E+11
MELT =      -1.E0      0.      0.      0.

TNT      RHDS =      1.56E0      CFP = 000 DPY = 012      NCDN = 0
EQST =      1.E0      0.      1.E0      1.44E0      1.44E0      0.
QEXPL =      4.520E+10 0.0625E0      2.0
TENS =      -1.E0      0.      -1.000E+11
MELT =      -1.E0      0.      0.      0.      0.

AL6061-T6 RHDS =      2.707E0      CFP = 000 DPY = 001      NCDN = 0
EQST =      6.670E+11 1.000E+12 1.220E+11 2.04E0      0.25E0      0.
YIELD =      3.210E+09 2.670E+11 3.790E+10

NLAYER =      4 JMAT =      1      2      3      4
NZONES= 1      80 CELLS IN 10.0      CM
NZONES= 1      24 CELLS IN 3.0      CM
NZONES= 1      24 CELLS IN 3.0      CM
NZONES= 1      50 CELLS IN 6.0      CM
7/8/9

```

FIGURE C.16 INPUT DECK FOR A RUNNING DETONATION THROUGH THREE EXPLOSIVES, ILLUSTRATING THAT PUFF PERMITS OVERDRIVING OF EXPLOSION

```

IDENT = DC5-A-1 SINTERED AL2O3 WITH BE AT FRONT
C AUTOMATIC REZONING EVERY 30 CYCLES
C X-RAY DEPOSITION HAS BEEN CALCULATED BY -FSCATT- AND PROVIDED AS A
C DEPTH-DOSE PROFILE FOR THE PUFF CALCULATION.
NTEDIT = 1 NJEDIT = 1 NREZONE = -30
TEDIT = 5.000E-09
JEDITS = 5 17 26 40 48 61 66 68 70 72 74 76 78 80
DTMAX = 5.000E-09 TREZON = 5.000E-09
NEGIT = 30 JCYCS = 200 CKS = 2.0 TS = 1.500E-06
NMTRLS = 3 MATFL = 0 UZERO = 0.

BERYLLIUM RHUS = 1.85E0 CFP = 000 DPY = 001
EQST = 1.203E+12 1.524E+12 3.550E+11 1.45E0 2.500E-01 5.130E+11 0.
MELT = 3.955E+10 1.978E+10 1.500E-01 2.500E-01-6.000E-02 4.500E-01

ALUMINA SINTERED RHDS = 3.969 CFP = 001 DPY = 004
EQST = 2.655E+12 4.200E+12 3.080E+11 1.320E+00 2.500E-01 2.090E+12
RHO = 3.16E0
AK = 1.700E+12 MUP = 1.000E+12 Y0 = 3.000E+09
NREG = 3
RHOP = 2.8E0 3.E0 3.92E0 4.44E0 4.44E0 4.5E0
C1 = .050 .050 .050 .050 .050 .050
P1 = 3.000E+10
1P2 = 5.000E+10 DELP = 0.
2P2 = 1.400E+11 DELP = -2.500E+10 YADDP = 1.000E+10
3P2 = 3.350E+11 DELP = -2.200E+10 YADDP = 1.000E+10
MELT = 4.500E+10 1.350E+10 2.000E-02 .9 .2
YIELD = 6.600E+10 1.600E+12
TENS = -1.000E+09-1.000E+09-1.000E+11
VISC = 2.0 .02

C-7 RHDS = 1.190 CFP = 000 DPY = 001
EQST = 7.816E+10 1.956E+11 8.000E+09 .79 .20 2.213E+11
EMELT = 6.000E+09 4.000E+09 .1 .6 -.15

NLAYERS= 4 JMAT = 1 2 3 3
NZONES= 1 31 CELLS IN .1 CM DX = .0076 RATIO = .935
NZONES= 1 31 CELLS IN .1 CM DX = .001 RATIO = 1.07
NZONES= 1 17 CELLS IN .15 CM DX = .01 RATIO = 1.07
NZONES= 1 30 CELLS IN .50 CM
NSPEC = 1 ANGLE = 0.
SPEC DC NARB ECAL = 200. START = 0. SSTOP = 3.000E-09

IDENT = DC5 AL2D3 TH = NP= 7 (8E10.3)
0. 1.073E+01 8.333E-03 9.178E-01 1.667E-02 6.342E-01 2.500E-02 4.954E-01
5.000E-02 3.090E-01 7.500E-02 2.317E-01 1.000E-01 1.866E-01
IDENT = DC5 AL2D3 TH = NP= 13 (8E10.3)
1.000E-01 6.638E+00 1.008E-01 5.319E+00 1.017E-01 4.480E+00 1.025E-01 3.895E+00
1.050E-01 2.871E+00 1.075E-01 2.334E+00 1.100E-01 2.002E+00 1.175E-01 1.473E+00
1.250E-01 1.208E+00 1.325E-01 1.041E+00 1.550E-01 7.652E-01 1.775E-01 6.230E-01
2.000E-01 5.411E-01
IDENT = DC5 AL2U3 TH = NP= 7 (8E10.3)
2.000E-01 7.378E-02 2.250E-01 7.309E-02 2.500E-01 7.238E-02 2.750E-01 7.165E-02
3.000E-01 7.091E-02 3.250E-01 7.016E-02 3.500E-01 6.940E-02
IDENT = DC5 AL2D3 TH = NP= 7 (8E10.3)
3.500E-01 6.940E-02 4.333E-01 6.681E-02 5.167E-01 6.414E-02 6.000E-01 6.141E-02
6.833E-01 5.861E-02 7.667E-01 5.572E-02 8.500E-01 5.270E-02
7/8/9

```

FIGURE C.17 INPUT DECK FOR RADIATION INTO BERYLLIUM AND ALUMINA, SHOWING THE USE OF A DEPTH-DOSE PROFILE, GEOMETRIC LAYOUT, AND AUTOMATIC REZONING

```

IDENT 1002 X-RAY DEPOSITION INTO AL FOR POST TEST STUDY
C THE X-RAY DEPOSITION HAS BEEN CALCULATED BY -FSCATT- AND IS PROVIDED AS
C A DEPTH-DOSE PROFILE FOR THE PUFF CALCULATION
NTEDIT = 0 NJE0IT 2 NREZON = 0
JEDITS = 28 31 34 37 40 43 1 5 10 15 20 25 45 50
          SS 60 65 70
NE0IT = 30 JCYCS = 150 CKS = 2.000E+01 TS = 5.000E-07
NMTRLS = 1 MATFL = 0 UZERO = 0.

AL 1145 RHQS = 2.7E0 CFP = 010 DPY = 003
EQST = 7.600E+11 1.500E+12 1.220E+11 2.04E0 2.500E+01 0. 0.
DFRI 1145-1.000E-02-4.000E+09 1.000E-04 3.000E+09-3.000E+09-4.000E+09 0.
VISC = 4.000E0 5.000E-02 0. 0. 0. 0. 0.
YIELD = 2.000E+09 3.000E+11 0. 0. 0. 0. 0.
MELT = 6.59CE+09 2.400E+09 1.500E-01 2.500E-01-6.000E-02 0.

NLAYERS = 1 JMAT 1
NZONES= 3 27 CELLS IN 1.100E-01 CM OX = 3.500E-03 RATIO = 9.500E-01
          17 CELLS IN 3.400E-02
          27 CELLS IN 1.100E-01 CM CX = 1.000E-03 RATIO = 1.05E0

NSPEC = 1 ANGLE = 0.
DQPOST NARB 0 ECAL = 7.440E+02 START = 0. SSTOP = 5.000E-09
IDENT=DQPOST NOS. TH = NP = S (8E10.3)
2.413E0 6.108E-02 2.476E0 5.707E-02 2.54E0 5.335E-02 2.603E0 4.981E-02
2.667E0 4.978E-02
7/8/9

```

FIGURE C.18 INPUT DECK FOR RADIATION INTO ALUMINUM, SHOWING A DEPTH-DOSE PROFILE AND MULTIPLE ZONES IN ONE LAYER

```

IDENT = 610 200 CAL RADIATION WITH SPECTRA IN 3 TIME INCREMENTS
C THE RADIATION HAS BEEN SEPARATED INTO A SERIES OF BLACK BODY RADIATORS
C EACH WITH ITS OWN TEMPERATURE AND TIME OF DEPOSITION.
NTEDIT = 9 NJEDIT = 1 NREZON = 4 NALPHA = 1
TEDIT = 1.000E-08 1.000E-07 2.000E-07 4.000E-07 7.000E-07 1.000E-06 1.400E-06
        2.000E-06 3.000E-06
JEDIT = 25 42 54 100 128 142
NTR = 2 3 4 5
JREZON = 45 60 80 110
NEOIT = 50 JCYCS = 200 CKS = 6.E0 TS = 6.000E-06
NMTRLS = 1 MATFL = 0 UZERU = 0.

ALUMINUM RHOS = 2.785E0 CFP = 000 DPY = 004 NCUN = 1
EQST = 7.550E+11 1.290E+12 1.220E+11 2.04E0 2.500E-01 1.197E+12 3.110E+10
TENS = -2.000E+10 0. -2.000E+10
COSQ = 3.24E0 2.500E-01 0.
Y0 = 2.500E+09 2.870E+11
EMELT = 1.060E+10 2.400E+09 1.500E-01 2.500E-01 -6.000E-02
ALUMINUM ITAPE = 5 PBW = 1.
ALUMINUM X-RAY ABS NOE = 2 ATWT = 26.98
EDGEI = 1.00000E 0, 1.56000E 0
COEF1 1.08710E 1, -2.78415E 0, 1.89848E -1, .00000E 0
COEF2 1.31739E 1, -2.18214E 0, -2.58940E -1, 2.22834E -2

NLAYERS = 1 JMAT = 1
NZONES = 3 40 CELLS IN 1.224E-02 CM DX = 1.000E-04 RATIO = 1.051E0
          33 CELLS IN 5.776E-02 CM DX = 7.187E-04 RATIO = 1.05E0
          76 CELLS IN 2.93E0 CM DX = 3.618E-03 RATIO = 1.05E0

NSPEC = 3 ANGLE = 0.
NHNU NBB = 1 ECAL = 4.2E0 START = 0. SSTOP = 3.500E-09
200 CAL TEMP = 3.7E0 ECAL = 4.2E0
NHNU NBB = 1 ECAL = 8.7E0 START = 3.500E-09 SSTOP = 4.500E-09
200 CAL TEMP = 2.370 ECAL = 8.7E0
NHNU NBB = 1 ECAL = 1.380E+01 START = 4.500E-09 SSTOP = 5.500E-09
200 CAL TEMP = 2.08E0 ECAL = 1.380E+01
7/8/9

```

FIGURE C.19 INPUT DECK FOR RADIATION FROM THREE BLACK BODIES INTO ALUMINUM, SHOWING FOUR REZONES AND MULTIPLE ZONES IN ON ONE LAYER

```

IDENT = NEUTRON GEN/CONFIGURATION W/ZRCLY-2 CLADDING
NTEDT = 1 NJEDIT = 1 NREZDN = 0
TEDIT = 1.000E-09
JEDIT = 51.1.03.1.06.1.09.1.2.1.4.1.6.1.8.2.5.3.5.4.5
NEDIT = 5 JCYCS = 200 CKS = 10.E0 TS = 6.000E-06
NMTRLS = 4 MATFL = 0 UZERO = 0.

U-3PCTMO RHDS = 17.8608E0 CFP = 000 DPY = 004
EQST = 1.202E+12 1.459E+12 2.059E+10 2.03E0 2.500E-01 5.840E+12
MELT = 2.050E+09 1.271E+09 1.160E-01 5.000E-02 0.
YIELD = 9.100E+08 6.314E+11
TENS = -8.000E+09 -1.000E+11 0.
VISC = 4.E0 5.000E-02 5.000E-02

NA-600C RHDS = 8.080E-01 CFP = 000 DPY = 001
EQST = 3.200E+10 0.0 1.000E+11 1.0E0 2.500E-01
TENS = -1.000E+11 -1.000E+11 0.
ZIRCALOY-2 RHDS = 6.55E0 CFP = 000 DPY = 004
EQST = 9.031E+11 0. 6.714E+10 7.700E-01 2.500E-01 0.
EMELT = 6.615E+09 2.381E+09 -7.200E-02 2.400E-01 -6.000E-02
VISC = 4.E0 5.000E-02 5.000E-02
TENS = -1.000E+11 -1.000E+11 0.
YIELD = 3.000E+09 3.472E+11

NAK-100C RHDS = 8.470E-01 CFP = 000 DPY = 001
EQST = 5.300E+10 0.0 1.000E+11 1.0E0 2.500E-01
TENS = -1.000E+11 -1.000E+11 -1.000E+11

NLAYERS = 4 JMAT = 1 2 3 4
NZONES= 1 29 CELLS IN 5.350E-01 CM DX = 6.000E-03 RATID = 9.346E-01
NZONES= 1 3 CELLS IN 1.270E-02 CM
NZONES= 1 3 CELLS IN 2.540E-02 CM
NZONES= 1 12 CELLS IN 5.000E-02 CM

NSPEC = 1 ANGLE = 0.
PROTON NARB = 0 ECAL = 5.900E-01 START = 0. SSTOP = 2.000E-07
IDENT = U TH = NP = 4 (1P8E10.3)
0. 1.E0 2.000E-01 1.E0 4.000E-01 1.E0 5.350E-01 1.E0
IDENT = NA NPPOINTS = 3 (1P8E10.3)
0.E0 0.4E0 .00635E0 0.4E0 0.0127E0 0.4E0
IDENT = ZRCLY-2 NPPOINTS = 3 (1P8E10.3)
0.E0 0.4E0 0.0127E0 0.4E0 0.0254E0 0.4E0
IDENT = NAK NPPOINTS = 3 (1P8E10.3)
0. 0.4E0 0.02E0 0.4E0 0.05E0 0.4E0

H-DATA
H = 1 2 M H = 52 2 M

EXTRA
$NLIST RHOS(1)=1.845E+01,EQSTN(1)=1.55867E0,EHL(1)=30*1.065E+09$
7/8/9

```

FIGURE C.20 INPUT DECK FOR RADIATION BY A DEPTH-DOSE PROFILE INTO SEVERAL LAYERS AND ILLUSTRATING USE OF HDATA AND TEDITs

```

IDENT = 261A EXPONENTIAL LOADING ON A HEAT SHIELD
C THE LOADING IS APPLIED AS AN EXPONENTIAL PRESSURE ON THE FIRST BOUNDARY.
C PARAMETERS OF THE PRESSURE LOADING ARE READ IN THROUGH -EXTRA-.
NTEDT = 0 NJED1T = 2 NZEZON = 0
JED1TS= 1 11 22 33 43 54 65 75 86 97 107 118 129 139
        160 174 179 183
NED1T = 10 JCYCS = 120 CKS = 3.00 TS= 7.000E-06
NMTRLS= 3 MATFL = -2 UZERD= 0.

DTWR RHDS = 1.63E0 CFP = 000 DPY = 001 NCDN = 0
EQST = 7.490E+10 1.500E+11 1.600E+10 0.174E0 0.25E0 1.310E+11
YIELD = 2.400E+08 3.000E+10 0.

BDND RHDS = 1.1E0 CFP = 000 DPY = 000 NCDN = 0
EQST = 2.990E+10 1.588E+11 1.000E+10 0.5E0 0.25E0 -1.450E+11

AL6061-T6 PHDS = 2.707E0 CFP = 000 DPY = 001 NCDN = 0
EQST = 6.670E+11 1.000E+12 1.220E+11 2.04E0 0.25E0 0.
YIELD = 3.210E+09 2.670E+11 3.790E+10

NLAYER = 3 JMAT = 1 2 3
NZONES= 1 150 CELLS IN 1.016 CM
NZONES= 1 17 CELLS IN 0.076 CM
NZONES= 1 19 CELLS IN 0.254 CM

EXTRA
$NL1ST P6(1)=7.1E10, T6(1)=-0.385E-6 $
7/8/9

```

FIGURE C.21 INPUT DECK FOR PRESSURE LOADING ON A THREE-LAYERED PLATE, SHOWING USE OF THE NAMELIST STATEMENT

```

IDENT JIM GRANS SHOCK TUBE
NTEDT      C NJEDT      1      NALPHA      1
JEDIT =    P, 10,15,20,23,30
NEDIT      10 JCYCS      150 CKS      1.000E+03 TS      3.300E-03
NMTRLs      2 MATFL      -2 UZEPQ      0.

AIR          RHOS      1.169E-03 CFP      000 DPY      012
EQST        1.          0.          0.          .4          .4          0.
Q =          2.170E+09
TENS        -1.000E+10-1.000E+10-1.000E+10
VISC        4.          .02

STEEL        RHOS      7.903      CFP      000 DPY      001
EQST        1.648E+12 2.932E+12 7.360E+10 1.17      .25      4.658E+12
YIELD        7.013E+09 7.892E+11

NLAYER      2 JMAT      1      -2
NZONES 1      30 CELLS IN 15.5      INCH
NZONES 1      5 CELLS IN 25.      CM

EXTRA
$NLIST P6(1)=1.379E7,T6(1)=-1.,RHOS(2)=7.902995137$
7/8/9

```

FIGURE C.22 INPUT DECK FOR SIMULATING AN AIR SHOCK BY APPLYING A PRESSURE BOUNDARY THROUGH NAMELIST

The material properties give samples for ductile fracture (DFRACT in Figures C.3, C.7, and C.18), brittle fracture (BFRACT in Figure C.8), and shear banding (SHEAR2 in Figures C.11 and C.12). Porous materials are modelled by POREQST in Figures C.6, C.9, C.13, and C.17 and by CAP1 in Figures C.10 and C.14. The composite model REBAR is used in Figure C.10. The tabular equation of state EOSTAB is used for PETN in the data deck in Figure C.14. Explosives are treated in various ways in Figures C.11, C.12, C.14, C.15, and C.16.

In the layout, most materials are treated with uniform size cells. However, multiple zones within a layer are used in Figures C.15, C.18, and C.19. The geometric cell layout is featured in Figures C.5, C.8, C.14, C.15, and C.17 through C.20. Gaps between layers occur in Figures C.13 and C.15. A large number of layers (up to 30) are permitted as shown in Figure C.10. For planar geometry, an infinite boundary may occur at the first or last coordinate by making the first or last JMAT value negative as shown in Figure C.22. For convenience, the thickness dimension may be inserted in English units if columns 41 to 45 contain the letters "_INCH" (See Figures C.11 and C.22). GENRAT changes the dimensions to centimeters for internal use and for printing later. Depth-dose profiles are shown in Figures C.17, C.18, and C.20; black body x-ray spectra appear in Figure C.19 and an arbitrary spectrum in Figure C.5.

The EXTRA and HDATA lines following the normal data deck permit many special features. In Figure C.3, the EXTRA line provides the internal energy for the hot aluminum and resets the density to its normal value for the equation-of-state calculations. A similar effect is illustrated in Figure C.20. In Figures C.14, C.21, and C.22 a pressure boundary is provided by specifying P6 and T6. A preload is given in Figure C.14. A simultaneous detonation of EL-506D is provided in Figure C.15 by the insertion of internal energy through the EXTRA line. In Figure C.22, the air is initialized at a moderate pressure by providing it with some internal energy (treating it as an explosive undergoing a simultaneous detonation), and the steel is preloaded by decreasing the density in the EXTRA line. Figure C.20 contains a data deck with both

EXTRA and HDATA lines. The HDATA line sets the boundary indicators to the MIRROR case to simulate a fixed or reflecting boundary on both sides.

Appendix D

FMELT: THERMAL REDUCTION FUNCTION

The subroutine FMELT is used to reduce the strength and shear moduli as a function of the internal energy. FMELT contains two functions. The first (F) normally affects the yield strength, spall strength, and the amplitude of the compaction surface in porous materials. The second function (FG) reduces the shear modulus.

FMELT is called in GENRAT for initialization, and in HSTRESS to compute the nondimensional reduction factors.

Formulation of the Model

The strength reduction and modulus reduction factors are presumed to have the form shown in Figure D.1 for several grades of aluminum. The reduction factor is described by a series of parabolas as illustrated in Figure D.2. Up to three parabolas are used. Each parabola is defined by the coordinates of its end points plus the amplitude at its midpoint. These input quantities are transformed to coefficients of the series for F. In the i th interval, the coefficients are

$$F = F_{ai+1} + F_{bi+1} E + F_{ci+1} E^2$$

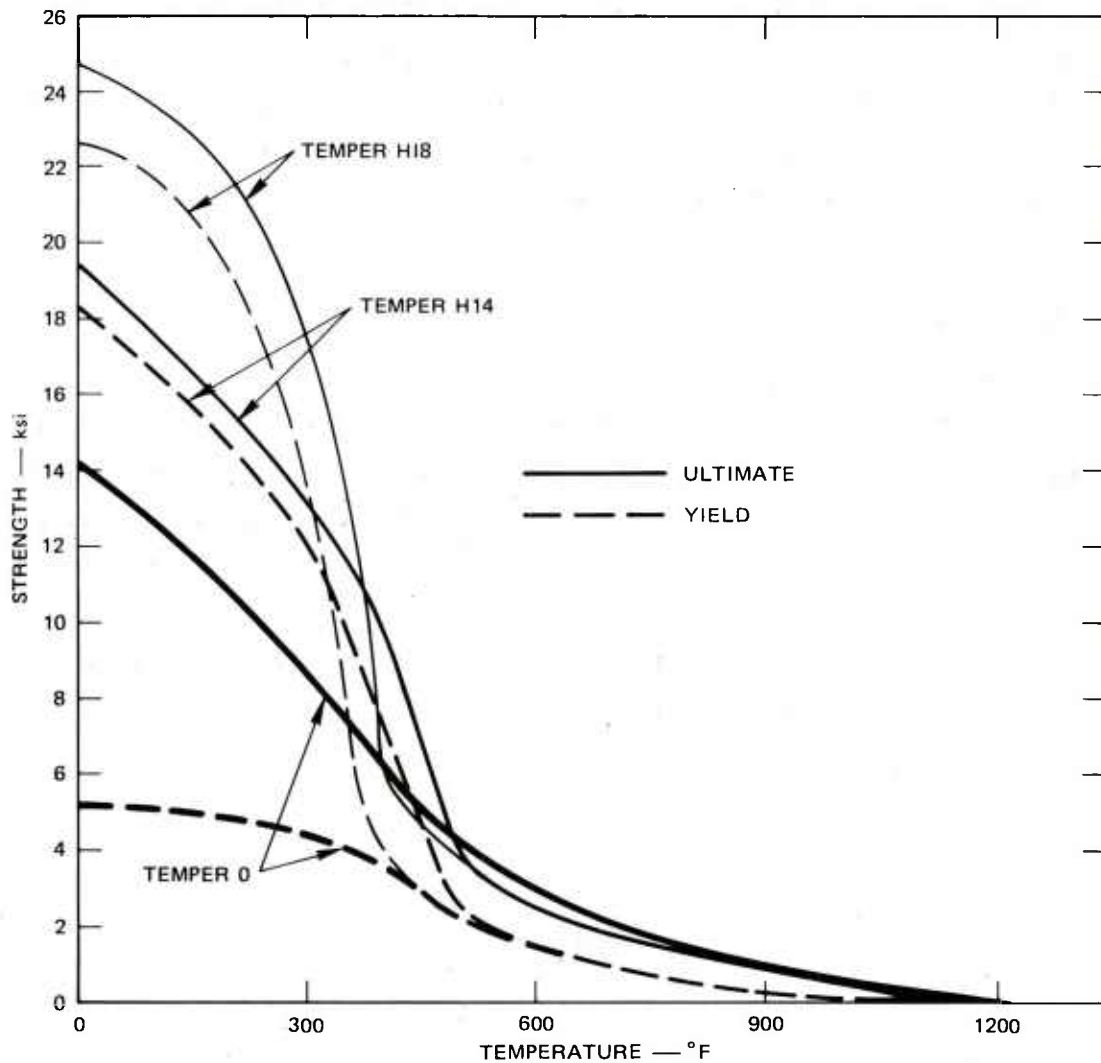
where

$$F_{ai+1} = F_{Li} - E_{Li} (F_{Ri} - F_{Li} + 4\Delta F \cdot E_{Ri} / \Delta E) / \Delta E$$

$$F_{bi+1} = (F_{Ri} - F_{Li}) / \Delta E + 4\Delta F (E_{Li} + E_{Ri}) / \Delta E^2$$

$$F_{ci+1} = -4\Delta F / \Delta E^2$$

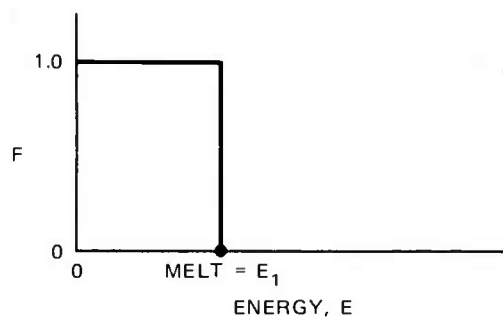
$$\Delta E = E_{Ri} - E_{Li}$$



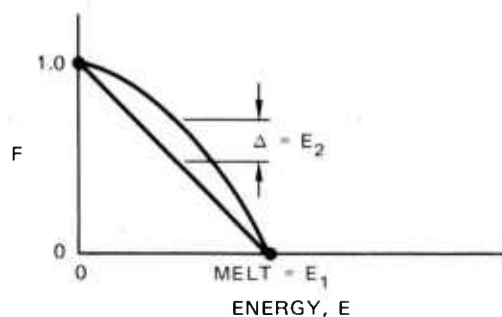
SOURCE: Metals Handbook, Vol. I, (American Society of Metals, 1961), pp. 936, 940.

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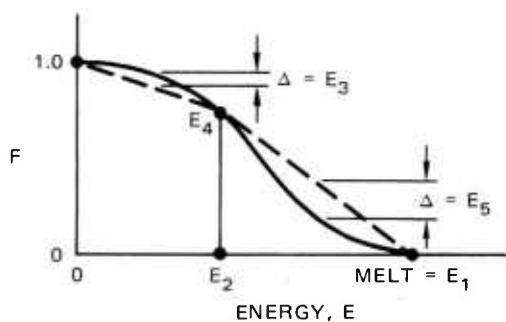
FIGURE D.1 VARIATION OF STRENGTH WITH TEMPERATURE FOR ALUMINUM 1100



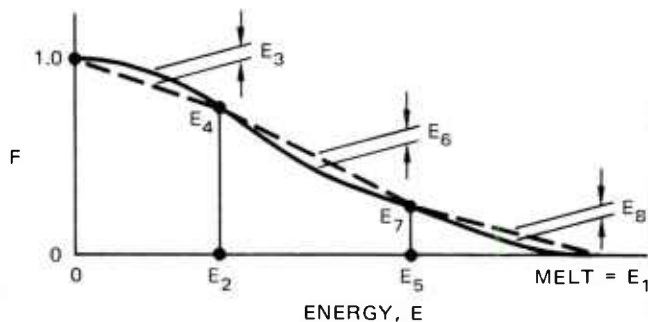
NO PARABOLIC REGIONS



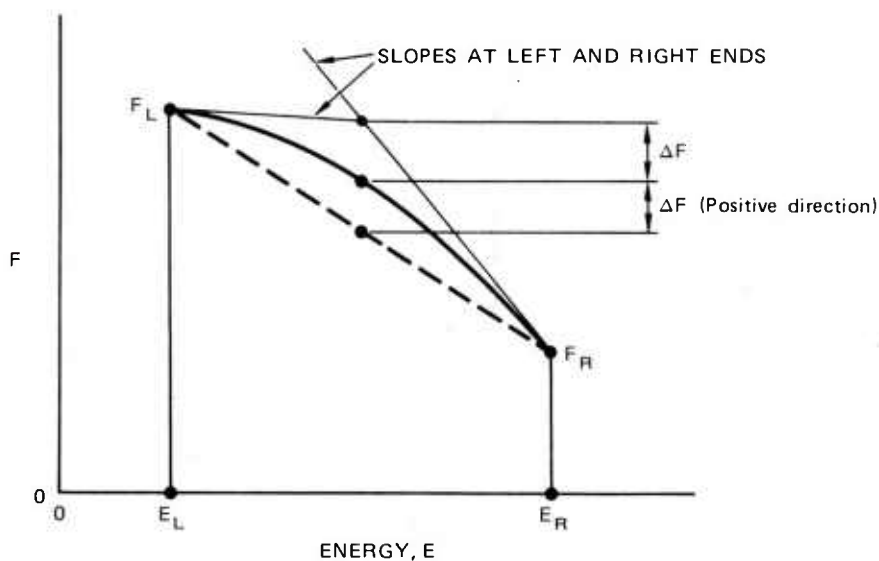
ONE PARABOLIC REGION



TWO PARABOLIC REGIONS



THREE PARABOLIC REGIONS



STANDARD PARABOLA AND DEFINITION OF TERMS IN DERIVATION

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FIGURE D.2 DEFINITION OF INPUT FOR THERMAL STRENGTH AND MODULUS REDUCTION FUNCTION

E_{Ri} , E_{Li} , F_{Ri} , F_{Li} = energies and amplitudes on the right and left sides of the interval

ΔF = the offset of the midpoint of the parabola from a straight line, as shown in Figure D.2.

Sample inputs for the strength and modulus reduction factors are listed in Appendix C.

Several options are available to the user with the FMELT function. From zero to three parabolas may be used to define the function. The number is determined automatically by the number of input values used. Both strength and modulus reduction functions may be used or only the strength reduction function. If only the strength reduction function is supplied, the same function is used for modulus reduction.

The data are supplied as a series of numbers designated E_1 , $E_2 \dots E_8$ in Figure D.2. The first parameter E_1 is always the melt energy in erg/g. The other parameters vary in significance according to the number of parabolas as shown in Figure D.2. The sign convention for ΔF and the slopes at the end of the parabolic segment are shown in the last diagram of D.2. The slopes of the parabola at its ends are determined graphically by passing straight lines through the end points and a point $2\Delta F$ from the midpoint of the straight line segment as shown. It is advisable to examine the slopes to verify that the chosen parabola matches the experimental data adequately and does not contain a local minimum or maximum.

Appendix E

RESIZING THE CELLS: REZONE

The purpose of rezoning is to give the cells an optimum size distribution for the hydrodynamic calculations. During the radiation deposition or shortly after impact (first part of the calculation), the cells near the radiated face or near the impact interfaces should be small to correctly depict the wave motion at those points. Later on, as the waves spread out, the presence of the small cells merely slows down the hydrodynamic computations. Therefore, REZONE is called to gradually increase cell size (the current REZONE does not decrease size). As outlined in Section 5.1, rezoning begins either at the right boundary (negative NREZON) or at JREZON (positive NREZON) and sweeps to the left, resizing groups of cells to obtain the desired size. If cells are already larger, they are unaffected. Because there are fewer cells following each rezoning, the initial coordinate, JINIT, is increased by each call to REZONE.

The following guidelines were used in calculating the redistribution of coordinates:

- Boundaries must remain as coordinate points
- JEDIT locations (Lagrangian coordinates at which printouts are requested) should not be disturbed.
- Cell thicknesses should not be allowed to vary rapidly in a material.
- Across boundaries, the cell thicknesses should vary so that the crossing time of a wavelet is the same across any cell; that is,

$$\frac{\Delta X_1}{C_1} = \frac{\Delta X_2}{C_2} \quad (E.1)$$

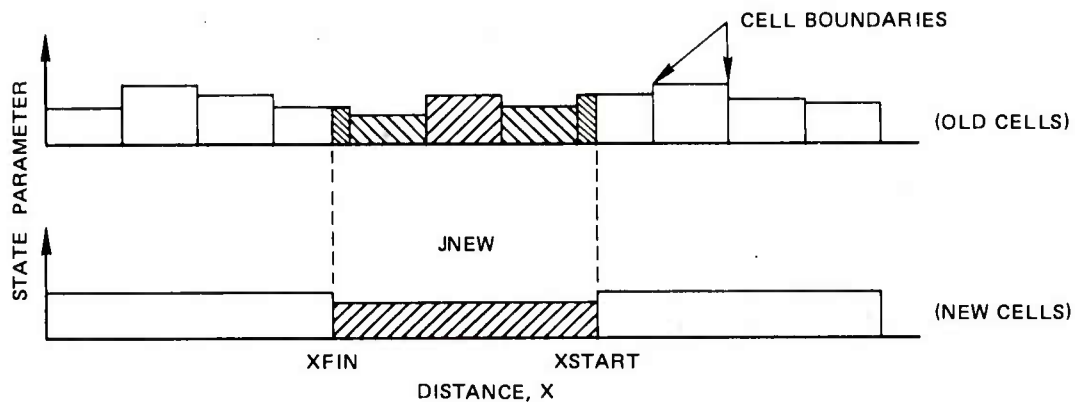
where

$\Delta X_1, \Delta X_2$ = cell thicknesses
 C_1, C_2 = sound speeds.

- Smoothing of the wave should be minimized. For cell-centered quantities (SHL, PHL, EHL, etc.) this is accomplished by weighting the old cell quantities according to their contribution of mass to the new cell. For example, the new internal energy is computed from

$$E_{\text{NEW}} = \frac{\sum E_{\text{OLD}} \rho \Delta X}{\sum \rho \Delta X} \quad (\text{E.2})$$

- As illustrated in Figure E.1, the summations are carried out from XSTART to XFIN, the boundaries of JNEW. For coordinate-centered quantities, such as U, a more complicated technique is required, as explained later.
- Neglect conservation of kinetic energy. Because cells are usually larger when rezoned, this neglect will lead to some loss of total energy.



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FIGURE E.1 LAYOUT FOR COMPUTING PROPERTIES AT REZONED COORDINATES

The subroutine that was constructed to perform the rezoning is naturally separable into three parts: one to locate the initiation point of rezoning, one to select rezonable sets of cells, and one to compute the new cell properties. In the first part of the subroutine, the control variable (JTS for NREZON < 0 and JREZON for NREZON > 0) is located with respect to material boundaries. A possible layout of the coordinates is shown in Figure E.2. (JEDITS need not be in numerical order.)

Coordinates are not all rezoned at once, but in groups between JEDIT, material boundaries, and spall planes. The second part of the sub-routine searches for these rezonable groups of coordinates. Figure E.3 defines some nomenclature used in the searching process.

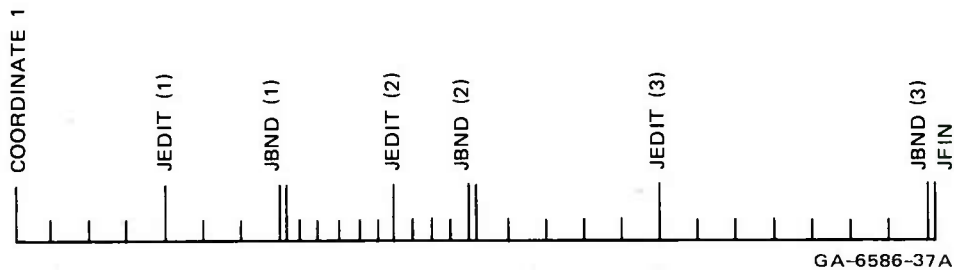


FIGURE E.2 REPRESENTATIVE LAYOUT OF COORDINATES BEFORE REZONING

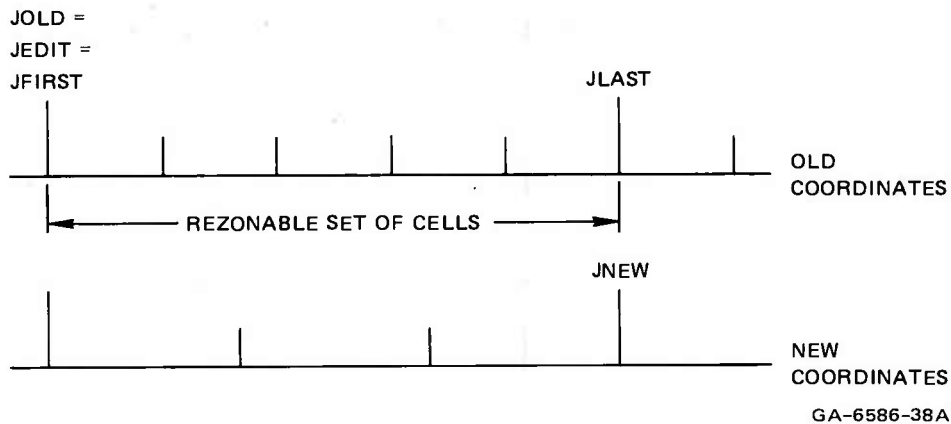


FIGURE E.3 REZONABLE SET OF CELLS TERMINATED ON LEFT BY A JEDIT

In the third part of the program, the rezonable set of cells is tested before rezoning. If the number of cells ahead is less than the number that would be obtained in the rezoning, a check is made to determine whether a region of small cells is followed by a region of large cells in the rezonable set. (This is likely in a radiation problem because the surface material expands.) If there is a region of small cells, the rezonable set is truncated to include only those small cells, and rezoning is performed. If the numbers of new cells and old cells are equal and the old cells have a fairly uniform thickness, then the coordinates are simply renumbered. If computation of new properties is called for, the calculations are performed as described in the guidelines above. If the rezonable set of cells is terminated at the left by a boundary or spall surface, then the new coordinate at JFIRST is included in the computation of the current set of cells. For other termination conditions of the rezonable set, new properties are computed up to, but not including, the new coordinate at JFIRST. Those properties will be computed with the next rezonable set.

Conservation of Momentum: Velocity Computation

Several approaches are available for conserving total momentum in computing the new particle velocity array. Because the velocity array is associated with the coordinate points, the approach used was to compute a momentum associated with each coordinate. The requirements for the computation were to:

- Preserve momentum exactly.
- Leave the velocity unaltered if the cell dimensions on both sides of the coordinate are unchanged.

The momentum associated with a coordinate is computed by weighting the momenta near the new coordinate in proportion to the distance from the coordinate.

The momentum is separated into two components: a term proportional to the average momentum (the usual momentum term) and a term related to the variation of momentum across the cell:

$$M_{12} = M_{a12} + M_{b12} \quad (E.3)$$

$$M_{a12} = 1/2 \int_{X_1}^{X_1 + \Delta X} \rho u d\xi \quad (E.4)$$

$$M_{b12} = - \frac{3}{\Delta X} \int_{X_1}^{X_1 + \Delta X} \rho u (\xi - X_1 - \frac{\Delta X}{2}) d\xi \quad (E.5)$$

where

M_{a12} = one-half the momentum of the cell between coordinates 1 and 2

M_{b12} = the contribution to coordinate 1 of the variation of momentum in the cell 1-2

X_1 = the location of coordinate 1

ΔX = the dimension of cell 1-2.

The coefficient $(-3/\Delta X)$ and weight factor $(\xi - X_1 - \frac{\Delta X}{2})$ in M_{b12} were determined by requiring that $M_{b12} = 0$ if ρu is uniform in the cell and that the velocity U_1 be unchanged if the cell size is unchanged. The new velocity will be computed from

$$U_1 = 2 \frac{M_{12} + M_{01}}{(Z_{12} + Z_{01})} \quad (E.6)$$

where Z_{12} is the mass of the cell between coordinates 1 and 2.

To keep U_1 unchanged, M_{12} must be a function of U_1 only. The momentum at coordinate 2 from cell 1-2 is

$$M_{21} = M_{a12} - M_{b12}$$

As an example, consider a cell bounded by coordinates with velocities U_1 and U_2 . Then the velocity at any point is

$$U = U_1 + (U_2 - U_1) \frac{\xi - X_1}{\Delta X} \quad (E.7)$$

and $M_{a12} = 1/4 \rho \Delta X (U_1 + U_2)$

$$M_{b12} = 1/2 \rho \Delta X (U_1 - U_2)$$

Hence,

$$M_{12} = 1/2 \rho \Delta X U_1$$

$$M_{21} = 1/2 \rho \Delta X U_2$$

The more general problem is one in which a portion (from X'_1 to X'_2) of an old cell contributes to a new cell. The velocities at the boundaries of this portion are computed from

$$U'_1 = U_j + (U_{j+1} - U_j) \frac{X'_1 - X_j}{X_{j+1} - X_j} \quad (E.8)$$

$$U'_2 = U_j + (U_{j+1} - U_j) \frac{X'_2 - X_j}{X_{j+1} - X_j} \quad (E.9)$$

where the U and X quantities with j subscripts refer to the old cell velocities and locations. Let

$$\xi_1 = \frac{X'_1 + X'_2}{2} - X_1 - \frac{\Delta X}{2} \quad (E.10)$$

the distance between centroids of the contributing portion of the old cell and of the new cell; $\xi_2 = X'_2 - X'_1$, the contributing portion of the old cell. Then the momentum contributions of the portion are

$$M_{a12} = \frac{1}{4} \rho \xi_2 (U'_1 + U'_2) \quad (E.11)$$

$$M_{b12} = -\frac{1}{4} \frac{\rho \xi_2}{\Delta X} [6\xi_1 (U'_1 + U'_2) + \xi_2 (U'_2 - U'_1)] \quad (E.12)$$

In the code these two momentum quantities are AMAVG and AMSLP. The sums and differences are stored in the MOM array.

Detailed Treatment of Coordinate Arrays

The coordinate arrays may be divided into four groups according to their reference point (cell or coordinate) and numerical or nonnumerical character. The cell quantities are sound speed, density, internal energy, pressure, stresses, yield strength, mass, $H(J,1)$, $H(J,3)$, and other variables associated with the material model. The H quantities are

integers used as indicators; consequently, they cannot be handled by the weighting procedures otherwise appropriate. Density DHL is computed from the mass ZHL, rather than directly by averaging.

The coordinate quantities are X, T, U, and H(J,2). U is computed as described in the previous subsection. T, the spall strength, is set to the initial value TENS(M,1) except at interfaces and spall planes. There it is set to the corresponding T value in the unrezoned array. H(J,2) indicates spall or interface conditions at a coordinate. It is reset in the second (searching) portion of REZONE following computation of new cell quantities.

Printout

Some printout is obtained from each major step in REZONE. Therefore, if problems arise because of rezoning, they can usually be quickly traced.

Appendix F

ONE-DIMENSIONAL CYLINDRICAL AND SPHERICAL FLOW

The basic wave-propagation relations for one-dimensional geometry are derived here for cylindrical and spherical flow. Included are the mass and momentum conservation equations, expressions for the internal energy, elastic-plastic stress-strain relations, and spall equations.

Kinematic Calculations

The equations for mass and momentum conservation and the expressions for internal energy are derived here.

For spherical flow, consider two finite-difference cells bounded by radii r_1 , r_2 , and r_3 and subtending an arc of $d\theta$ in orthogonal circumferential directions as shown in Figure F.1. The mass of cell 1 is

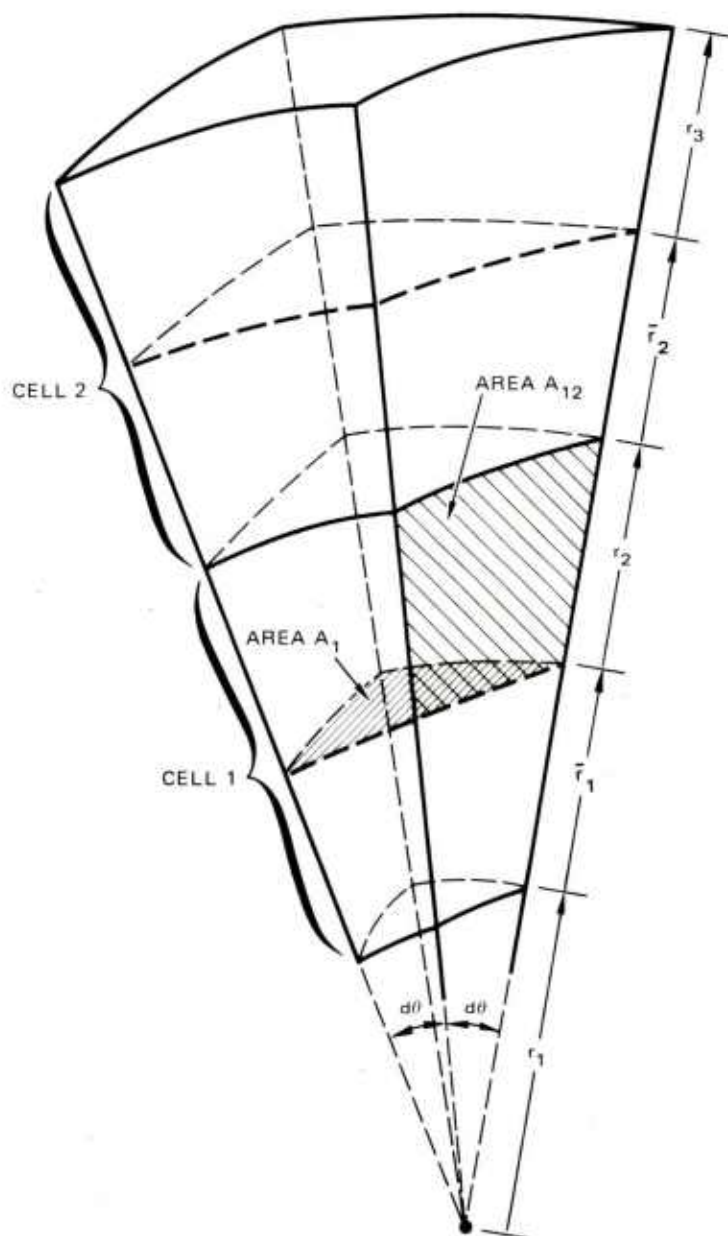
$$M_1 = \frac{\rho_0}{3} d\theta^2 (r_2^3 - r_1^3) \quad (F.1)$$

Mass conservation is provided by storing $Z_1 = M_1/d\theta^2$ as a constant for cell 1. Then the density at any time is

$$\rho = \frac{3Z_1}{r_2^3 - r_1^3} \quad (F.2)$$

Conservation of momentum is the basis for determining the velocities of cell boundaries. The mass associated with each boundary point is half the mass in the two adjacent cells. The forces acting on this mass are computed from the stresses in the adjacent cells and the areas they act on. The stress in the cell between r_1 and r_2 acts at a mid-mass radius given by

$$r_1^3 = \frac{r_2^3 + r_1^3}{2} \quad (F.3)$$



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FIGURE F.1 CELL GEOMETRY CONSIDERED FOR ONE-DIMENSIONAL SPHERICAL MOMENTUM CALCULATIONS

and thus on the area A_1 shown in Figure F.1

$$A_1 = d\theta^2 \bar{r}_1^2 \quad (F.4)$$

The radial component of the tangential stress is $\sigma_{\theta 1} d\theta/2$, which acts on the area A_{12} on each side of the cell in Figure F.1:

$$A_{12} = \frac{\bar{r}_1 + r_2}{2} (r_2 - \bar{r}_1) d\theta \quad (F.5)$$

Assembling all the radial forces on the mass centered at r_2 and extending from \bar{r}_1 to \bar{r}_2 gives

$$\begin{aligned} & \sigma_{r1} d\theta \bar{r}_1^2 - \sigma_{r2} d\theta \bar{r}_2^2 + 4 \left[\sigma_{\theta 1} \frac{d\theta}{2} \left(\frac{\bar{r}_1 + r_2}{2} \right) (r_2 - \bar{r}_1) d\theta \right. \\ & \left. + \sigma_{\theta 2} \frac{d\theta}{2} \left(\frac{\bar{r}_2 + r_2}{2} \right) (\bar{r}_2 - r_2) d\theta \right] = \frac{\rho d\theta^2}{3} \frac{r_3^3 - r_1^3}{2} \frac{\Delta U_2}{\Delta t} \end{aligned} \quad (F.6)$$

Here ΔU_2 is the change in velocity of the coordinate r_2 . Elimination of $d\theta^2$ and use of Eq. (F.1) for the definition of the initial cell mass leads to

$$\Delta U_2 = \frac{6 \Delta t [\sigma_{r1} \bar{r}_1^2 - \sigma_{r2} \bar{r}_2^2 + \sigma_{\theta 1} (\bar{r}_1 + r_2) (r_2 - \bar{r}_1) + \sigma_{\theta 2} (\bar{r}_2 + r_2) (\bar{r}_2 - r_2)]}{Z_1 + Z_2} \quad (F.7)$$

In Eq. (F.7), the radial stresses are augmented by the artificial viscosity stresses for the momentum calculations. No artificial viscosity is added to the tangential stresses.

The change in internal energy that arises from the work done is

$$\Delta E = V \int \sigma d\epsilon = - \int P dV + V \sum_i \int \sigma_i d\epsilon_i \quad (F.8)$$

Through use of the stress and strain definitions in Section 4.1, the energy change reduces to

$$\Delta E = - \int \sigma_1 dV + \frac{3}{2} \int \sigma'_1 (dV + V d\epsilon_1) \quad (F.9)$$

This expanded form is convenient for computations because the first term is the expression for planar flow and the second is added only for spherical flow.

For cylindrical flow, the finite-difference cell is bounded by an inner radius r_1 and an outer radius r_2 , subtends an arc of $d\theta$, and has indefinite extent in the Z direction. Motion occurs only in the radial direction. The mass of the cylindrical cell is

$$M_1 = \frac{\rho_0}{2} d\theta (r_2^2 - r_1^2) \quad (F.10)$$

where the cell is assumed to have unit length in the Z direction. Mass is conserved at each cell by storing the mass $Z = M/d\theta$ for each cell and computing the density ρ at any time from the geometry and Z as in Eq. (F.10):

$$\rho = \frac{2Z_1}{r_2^2 - r_1^2} \quad (F.11)$$

Momentum conservation follows the same plan as for spherical flow. First, a mid-mass radius is defined:

$$\bar{r}_1^2 = \frac{r_1^2 + r_2^2}{2} \quad (F.12)$$

The area of action of the radial stress at mid-cell is

$$A_1 = \bar{r}_1^2 d\theta \quad (F.13)$$

and the area for the circumferential stress $\sigma_{\theta 1}$ is

$$A_{12} = d\theta(r_2 - \bar{r}_1) \quad (F.14)$$

Assembling all the radial forces on the boundary-centered mass at r_2 leads to

$$\begin{aligned} & \sigma_{r1} d\theta \cdot \bar{r}_1 - \sigma_{r2} d\theta \cdot \bar{r}_2 + \sigma_{\theta 1} d\theta (r_2 - \bar{r}_1) \\ & + \sigma_{\theta 2} d\theta (\bar{r}_2 - r_2) = \frac{\rho d\theta}{2} (r_3^2 - r_1^2) \frac{\Delta U_2}{\Delta t} \end{aligned} \quad (F.15)$$

Elimination of $d\theta$ and use of the definition of Z leads to

$$\Delta U_2 = 4\Delta t \frac{\sigma_{r1} \bar{r}_1 - \sigma_{r2} \bar{r}_2 + \sigma_{\theta 1} (r_2 - \bar{r}_1) + \sigma_{\theta 2} (\bar{r}_2 - r_2)}{Z_1 + Z_2} \quad (F.16)$$

As in spherical flow, the radial stresses in Eq. (F.16) are augmented by the artificial viscosity stresses; the tangential stresses are not.

The change in internal energy in cylindrical flow is computed from Eq. (F.8) with the aid of the stress and strain definitions in Section 4.1. The energy change is

$$\Delta E = - \int \sigma_1 dV + \int (\sigma'_1 - \sigma'_2) (dV + V d\epsilon_1) \quad (F.17)$$

The first term is the expression used for planar flow. The second term is simply added for cylindrical flow. This term is similar to the second term in Eq. (F.9) because $\sigma'_2 = -\sigma'_1/2$ in spherical flow.

The foregoing analyses have been implemented into the SRI PUFF code for one-dimensional wave propagation.

Elastic-Plastic Calculations for Planar, Cylindrical, and Spherical Geometries

In this section, the general elastic and plastic calculations of Appendix G are applied to one-dimensional flows with linear work-hardening.

In planar flow, strain occurs only in the direction of propagation, and the transverse strains ϵ_2 and ϵ_3 are zero. Such planar flow occurs during impact of flat plates and in response to a simultaneous detonation of an explosive over a plane. In cylindrical flow, only radial motion occurs. Thus radial and circumferential strains are nonzero but axial strain is zero. Cylindrical flow occurs in the response of long buried tunnels, pipe lines, and in fragmenting rounds or bombs. In spherical flow, the flow is all radial and the transverse strains are equal and nonzero.

The equations for one-dimensional flow are summarized in Table F.1. The deviator strain is defined as

$$d\epsilon'_1 = d\epsilon_1 - \frac{1}{3}(d\epsilon_1 + d\epsilon_2 + d\epsilon_3) \quad (F.18)$$

The equivalent shear strain quantities are derived from Eq. G.5. The expressions for the equivalent stress $\bar{\sigma}$ are from Eq. G.4.

For planar flow, stresses are found by first computing σ_1^N from

$$\sigma_1' = \sigma_1^N = \sigma_{10}' + \frac{4}{3}\mu\Delta\epsilon_1 \quad (F.19)$$

which can be obtained from Eq. (G.11) because $\Delta\epsilon_1' = \frac{2}{3}\Delta\epsilon_1$.

If σ_1^N exceeds $2Y_o/3$, then from Eq. (G.27)

$$\sigma_1' = \frac{M\sigma_1^N + 2G Y_o^*}{M + 3G} \quad (F.20)$$

where Y_o^* has the same sign as σ_1' and $|Y_o^*| = Y_o$, the yield strength

Table F.1

STRESS AND STRAIN QUANTITIES IN ONE-DIMENSIONAL FLOW

Quantity	Definitions		
	Planar	Cylindrical	Spherical
$d\epsilon_1$	$\frac{\partial u}{\partial x}$	$\frac{\partial u}{\partial r}$	$\frac{\partial u}{\partial r}$
$d\epsilon_2$	0	$\frac{u}{r}$	$\frac{u}{r}$
$d\epsilon_3$	0	0	$\frac{u}{r}$
$d\epsilon'_1$	$\frac{2}{3} d\epsilon_1$	$d\epsilon_1 - \frac{1}{3} \frac{d\rho}{\rho}$	$d\epsilon_1 - \frac{1}{3} \frac{d\rho}{\rho}$
$d\epsilon'_2$	$-\frac{1}{3} d\epsilon_1$	$-d\epsilon_1 + \frac{2}{3} \frac{d\rho}{\rho}$	$-\frac{1}{2} d\epsilon_1 + \frac{1}{6} \frac{d\rho}{\rho}$
$d\epsilon'_3$	$-\frac{1}{3} d\epsilon_1$	$-\frac{1}{3} \frac{d\rho}{\rho}$	$-\frac{1}{2} d\epsilon_1 + \frac{1}{6} \frac{d\rho}{\rho}$
$d\bar{\epsilon}$	$\frac{2}{3} |d\epsilon_1|$	$\sqrt{\frac{4}{3} [d\epsilon_1^2 - d\epsilon_1 \cdot \frac{d\rho}{\rho} + (\frac{1}{3} \frac{d\rho}{\rho})^2]}$	$|d\epsilon'_1|$
$d\bar{\epsilon}^P$	$|d\epsilon_1^P|$	$\sqrt{\frac{4}{3} [(d\epsilon_1^P)^2 + (d\epsilon_2^P)^2 + d\epsilon_1^P d\epsilon_2^P]}$	$|d\epsilon_1^P|$
$\bar{\sigma}$	$\frac{3}{2} |\sigma'_1|$	$\sqrt{3(\sigma_1'^2 + \sigma_2'^2 + \sigma_1' \sigma_2')}$	$\frac{3}{2} |\sigma'_1|$
σ'_2	$-\frac{1}{2} \sigma'_1$	-	$-\frac{1}{2} \sigma'_1$

Notes: Subscript 1 is in direction of propagation

2 is in θ direction in cylindrical flow
or any transverse direction for the other
two flows

3 is in third orthogonal direction

$\epsilon, \epsilon', \epsilon^P$ are strain, deviator strain, plastic strain, positive
in tension

$\sigma, \sigma', \bar{\sigma}$ are stress, deviator stress, equivalent or Mises stress

γ, γ^P are equivalent shear strain, equivalent plastic shear strain

u is displacement in the direction of motion

x, r is coordinate in the direction of motion

ρ is density.

at the previous time step. The plastic strain is found from Eq. (G.22), accounting in addition for the possibility that the increment includes the beginning of yielding.

$$\Delta \epsilon_1^P = \frac{2G\Delta \epsilon_1 - Y_o^* + \frac{3}{2} \sigma_{10}}{M + 3G} \quad (F.21)$$

and

$$Y = Y_o + M\Delta \epsilon_1^P = Y_o + \frac{3M}{2} |\Delta \epsilon_1^P|.$$

This result agrees with the fact that, for perfect plasticity ($M = 0$), the plastic strain is

$$\Delta \epsilon_1^P = \Delta \epsilon_1' = \frac{2}{3} \Delta \epsilon_1 \quad (F.22)$$

and there is no change in the elastic deviator strain.

For cylindrical flow, two deviator stresses σ_1^N and σ_2^N are calculated from Eq. (G.26) and then $\bar{\sigma}^N$ is evaluated from Eq. (G.4). If $\bar{\sigma}^N$ exceeds Y , then $\bar{\sigma}$ is reduced from $\bar{\sigma}^N$ as follows:

$$\bar{\sigma} = \frac{M\bar{\sigma}^N + 3GY_o}{M + 3G} \quad (F.23)$$

The individual deviator stresses are then calculated from Eq. (G.25):

$$\sigma_1' = \sigma_1^N \frac{Y}{\bar{\sigma}^N} \quad (F.24)$$

$$\sigma_2' = \sigma_2^N \frac{Y}{\bar{\sigma}^N} \quad (F.25)$$

where $Y = Y_o + M\Delta \epsilon_1^P$.

The plastic shear strain is obtained as in Eq. (F.21):

$$\Delta \bar{\epsilon}^P = \frac{3G\Delta \bar{\epsilon} - Y + \bar{\sigma}_o}{3G + M} \quad (F.26)$$

and from Eqs. (G.24) and (G.25):

$$\Delta \epsilon_i^P = \Delta \epsilon_i' - \Delta \epsilon_i^E = \Delta \epsilon_i' \left(1 - \frac{Y}{\bar{\sigma}_o N}\right) \quad (F.27)$$

For spherical flow, σ_1^N is first computed elastically as usual and compared with $2Y_o/3$. If yield has occurred,

$$\sigma_1' = \frac{M\sigma_1^N + 2GY_o^*}{M + 3G} \quad (F.28)$$

and the plastic strain is

$$\Delta \epsilon_1^P = \frac{3G\Delta \epsilon_1' - Y_o^* + \bar{\sigma}_o}{M + 3G} \quad (F.29)$$

Note that in spherical flow, the relations for σ_1' and $\Delta \epsilon_1^P$ are almost identical to those in planar flow.

The plastic strain energy is associated with work hardening, temperature rise, and thermal softening, and is used in some dislocation models. The plastic energy is defined as

$$\Delta E^P = V \sum_i \sigma_i' d\epsilon_i^P \quad (F.30)$$

where V is specific volume and ΔE^P is the increase in specific internal energy. For planar and spherical geometries, the energy change is

$$\Delta E^P = \frac{3}{2} V \sigma_1' d\epsilon_1^P \quad (F.31)$$

A convenient form for the energy change in the cylindrical case is

$$\Delta E^P = V [\sigma_1' (2d\epsilon_1^P + d\epsilon_2^P) + \sigma_2' (2d\epsilon_2^P + d\epsilon_1^P)] \quad (F.32)$$

Appendix G

DEVIATOR STRESS MODELS

This appendix gives a derivation for a three-dimensional deviator stress model including elastic, plastic, and work-hardening behavior. The plasticity model is then expanded to encompass strain rate effects.

Plasticity Relations for Mises-Type Models

A three-dimensional computational model was developed for yielding based on Reuss (incremental or flow) plasticity, Von Mises yield behavior, and work hardening (See Hill⁴⁵ for general background). The following four assumptions form the basis of the model:

1. The strain can be separated into an elastic and a plastic component at each step. As in elasticity, the stress is proportional to the elastic strain component

$$d\epsilon = d\epsilon^E + d\epsilon^P \quad (G.1)$$

2. According to Reuss, the shear (or deviator) stress in any direction is proportional to the increment of plastic strain in that direction. The mathematical formulation of the condition is

$$\frac{d\epsilon_{12}^P}{\sigma_{12}} = \frac{d\epsilon_{23}^P}{\sigma_{23}} = \frac{d\epsilon_{13}^P}{\sigma_{13}} = \frac{d\epsilon_{11}^P}{\sigma_{11}} = \dots = d\lambda \quad (G.2)$$

These relations provide for changes in the directions of the principal stresses. Inherent in Eq. (G.2) is the assumption that there is no volume change in plastic strain, i.e.,

$$d\epsilon_1^P + d\epsilon_2^P + d\epsilon_3^P = 0 \quad (G.3)$$

where the singly subscripted strains are principal.

3. The behavior is homogeneous and isotropic even with work-hardening. Because there is no directionality, the state can be defined completely by scalars. The chosen scalars are an effective stress $\bar{\sigma}$ and an effective strain $\bar{\epsilon}^P$, which are invariant under rotation and do not distinguish between the three principal directions. For convenience, the effective stress is chosen so that $\bar{\sigma} = Y$ at yield. The usual definition for the effective stress has the following forms:

$$\bar{\sigma} = \sqrt{\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]} \quad (G.4a)$$

$$= \sqrt{\frac{3}{2}[(\sigma'_1)^2 + (\sigma'_2)^2 + (\sigma'_3)^2]} \quad (G.4b)$$

$$= \sqrt{\frac{3}{2}[\sigma_x'^2 + \sigma_y'^2 + \sigma_z'^2 + 2(\tau_{yz}^2 + \tau_{zx}^2 + \tau_{xy}^2)]} \quad (G.4c)$$

$$= \sqrt{3[(\sigma'_1)^2 + (\sigma'_2)^2 + \sigma'_1 \sigma'_2]} \quad (G.4d)$$

where

$$= \sqrt{\frac{3}{2} \sigma'_{ij} \sigma'_{ij}}$$

$\sigma_1, \sigma_2, \sigma_3$ = principal stresses

$\sigma'_1, \sigma'_2, \sigma'_3$ = deviator stresses in the principal directions

$\sigma'_x, \sigma'_y, \sigma'_z$ = deviator stresses in the coordinate directions

τ = shear stress.

A similar definition is given to the effective plastic strain, $d\bar{\epsilon}^P$. The amplitude is fixed by requiring that $d\bar{\epsilon}^P = d\epsilon_1^P$ for any case where $d\epsilon_2^P = d\epsilon_3^P$. Then $d\bar{\epsilon}^P$ has the forms

$$d\bar{\epsilon}^P = \sqrt{\frac{2}{9}[(d\epsilon_1^P - d\epsilon_2^P)^2 + (d\epsilon_2^P - d\epsilon_3^P)^2 + (d\epsilon_3^P - d\epsilon_1^P)^2]} \quad (G.5a)$$

$$= \sqrt{\frac{2}{3}[(d\epsilon_1^P)^2 + (d\epsilon_2^P)^2 + (d\epsilon_3^P)^2]} \quad (G.5b)$$

$$= \sqrt{\frac{2}{3} \left[(d\epsilon_x^P)^2 + (d\epsilon_y^P)^2 + (d\epsilon_z^P)^2 + 2(d\epsilon_{xy}^P)^2 + 2(d\epsilon_{yz}^P)^2 + 2(d\epsilon_{zx}^P)^2 \right]} \quad (G.5c)$$

$$= \sqrt{\frac{4}{3} \left[(d\epsilon_1^P)^2 + (d\epsilon_2^P)^2 + d\epsilon_1^P d\epsilon_2^P \right]} \quad (G.5d)$$

$$= \sqrt{\frac{2}{3} d\epsilon_{ij}^P d\epsilon_{ij}^P}$$

where

$d\epsilon_1^P, d\epsilon_2^P, d\epsilon_3^P$ = plastic strains in the principal directions

$d\epsilon_x^P, d\epsilon_y^P, d\epsilon_z^P$ = plastic strains in the coordinate directions

$d\epsilon_{xy}^P, d\epsilon_{yz}^P, d\epsilon_{zx}^P$ = plastic shear strains (tensor components).

4. The yield condition describes yielding as a function ϕ of the second invariant J_2' of the deviator stress tensor

$$\phi = J_2' - \kappa^2 = 0 \quad (G.6)$$

where

$$J_2' = \frac{\bar{\sigma}^2}{3} = \frac{1}{6} \left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]$$

and κ is a constant (yield strength in pure shear). Yielding occurs when Eq. (G.6) is satisfied. Alternatively, the yield criterion can be expressed in terms of the equivalent stress $\bar{\sigma}$ and the yield strength Y in simple tension.

The preceding assumptions form the basis of a plasticity model with an "associated flow" rule. For such a model, both the stress-strain relations, Eq. (G.2), and the yield function, Eq. (G.6), employ the same function ϕ . That is, Eq. (G.2) can be put into the form

$$d\epsilon_{ij}^P = \frac{\partial \phi}{\partial \sigma_{ij}} d\lambda \quad (G.8)$$

In a model with an associated flow rule, the plastic strain vector in principal strain space is always normal to the yield surface in stress space; this condition introduces simplifications that will be used later.

Next we introduce the elastic stress-strain relations:

$$\sigma'_{ij} = 2G(\epsilon^E_{ij} - \frac{\delta_{ij}}{3} \Sigma \epsilon_{ii}) \quad (G.9)$$

For convenience, we can simplify Eq. (G.9) by defining a deviator strain similar to the deviator stresses:

$$\epsilon'_{ij} = \epsilon_{ij} - \frac{\delta_{ij}}{3} \Sigma \epsilon_{ii} \quad (G.10)$$

Then Eq. (G.9) takes the form

$$\sigma'_{ij} = 2G\epsilon'^E_{ij} \quad (G.11)$$

The plastic flow relations, Eq. (G.2), are now rewritten into a convenient form. If each term in Eq. (G.2) is put in the form $d\epsilon^P_{ij} = \sigma'_{ij} d\lambda$, squared, and all the equations are added, the result is

$$\frac{9}{4}(d\epsilon^P)^2 = \bar{\sigma}^2(d\lambda)^2 \quad (G.12)$$

Replacing this value for $d\lambda$ in Eq. (G.2) provides the convenient form

$$\sigma'_{ij} = \frac{2}{3}\bar{\sigma} \frac{d\epsilon^P_{ij}}{d\epsilon^P} \quad (G.13)$$

To complete the model, we will assume that work hardening, if it occurs, is a function only of the equivalent plastic strain. The increase in the yield strength is

$$dY = M d\epsilon^P \quad (G.14)$$

where M is the work-hardening modulus. Hence the work hardening assumed is independent of the direction of straining so that material remains isotropic during plastic flow.

The problem we face can now be formulated as: Given the total strain increments, the stress components at the previous time, and the yield strength, solve Eqs. (G.1), (G.3), (G.11), and (G.13) simultaneously for the stresses σ'_{ij} . To aid in visualizing this problem, we introduce a vector notation for both principal deviator stress and principal deviator strain:

$$\vec{\sigma} = \sigma'_1 \vec{i} + \sigma'_2 \vec{j} + \sigma'_3 \vec{k} \quad (G.15)$$

and similarly for strain $\vec{\epsilon}$. For elastic behavior, Eq. (G.11) shows that

$$\vec{\sigma} = 2G\vec{\epsilon} \quad (G.16)$$

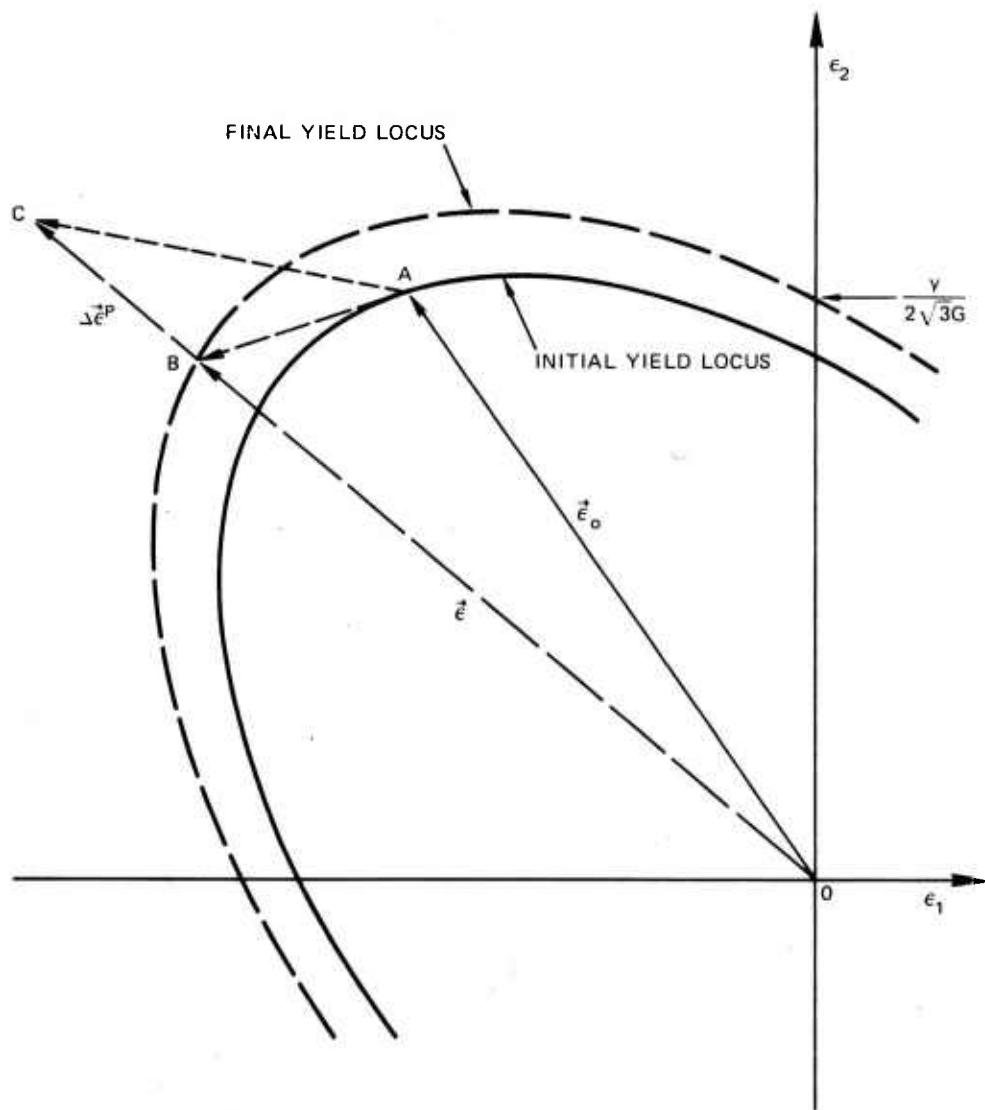
so that the two vectors are coaxial. The strain vectors are illustrated in Figure G.1 and we can imagine a corresponding stress diagram with the same directions, but magnified by $2G$. An initial yield surface is shown as the ellipse* defined by the elastic strain corresponding to $\bar{\sigma}_0 = Y_0$. The equation of the ellipse is given by Eq. (G.4d) and (G.11).

$$(\epsilon_1^E)^2 + (\epsilon_2^E)^2 + \epsilon_1^E \epsilon_2^E = \frac{Y_0^2}{12G^2} \quad (G.17)$$

Now strain increments are added to the components of the elastic strain deviator tensor defining point A to obtain a new tensor with components ϵ_{ij}

$$\epsilon_{ij} = \epsilon_{ijo}^E + \Delta\epsilon_{ij} \quad (G.18)$$

*In three-dimensional principal stress space the yield surface is a cylinder with its axis equiangular to the three principal directions and with radius $\sqrt{2/3} Y$. In principal deviator stress space, the yield locus is the circle on this cylinder with the center at the origin. When viewed parallel to the third axis, the circle appears as an ellipse in the 1, 2 plane.



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FIGURE G.1 VECTORIAL REPRESENTATION OF PRINCIPAL STRAINS DURING AN INTERVAL OF PLASTIC FLOW WITH WORK HARDENING

where none of these tensors is necessarily oriented in such a way that the components are principal. When the new total strain tensor is diagonalized to obtain the principal deviator strains, they define a new point C. (We take C to be outside the yield surface to illustrate yielding.) Because of the diagonalizations involved in proceeding from point A to C, a vector from point A to C does not have a simple relation to the strain increment tensor.

The new elastic strain state (and stress state) is given by the vector \vec{OB} which terminates on a yield surface which has expanded because of the work hardening. We can determine the coordinates of the point B by using the facts that

- The elastic strain vector is coaxial with the stress vector and has amplitude given by Eq. (G.16)
- The plastic strain increment vector is coaxial with the stress.

Then the plastic strain increment is

$$\begin{aligned}\Delta\vec{\epsilon}^P &= \vec{\epsilon} - \vec{\epsilon}^E \\ &= \vec{\epsilon} - \frac{\vec{\sigma}}{2G}\end{aligned}\tag{G.19}$$

where $\vec{\sigma}$ is the vector \vec{OB} and is proportional to the current yield value. With the aid of Eqs. (G.16) and (G.14), Eq. (G.19) can be transformed to a scalar equation because all the vectors are co-axial

$$\Delta\bar{\epsilon}^P = \bar{\epsilon} - \frac{1}{3G} (\bar{\sigma}_0 + M\Delta\bar{\epsilon}^P)\tag{G.20}$$

Here we used the facts derived from Eqs. (G.4b) and (G.5b) that

$$\bar{\epsilon} = \sqrt{\frac{2}{3}} |\vec{\epsilon}| \quad \text{and} \quad \bar{\sigma} = \sqrt{\frac{3}{2}} |\vec{\sigma}|\tag{G.21}$$

Solving for $\Delta\bar{\epsilon}^P$ provides

$$\Delta\bar{\epsilon}^P = \frac{3G\bar{\epsilon} - \bar{\sigma}_0}{M + 3G}\tag{G.22}$$

With $\Delta \bar{\epsilon}^P$ known, the yield value can be found from Eq. (G.14). The elastic strain is

$$\bar{\epsilon}^E = \bar{\epsilon} - \Delta \bar{\epsilon}^P \quad (G.23)$$

and the individual strains and stresses are

$$\epsilon'_{ij}{}^E = \epsilon'_{ij} \frac{\bar{\epsilon}^E}{\bar{\epsilon}} \quad (G.24)$$

$$\sigma'_{ij} = \sigma'_{ij}{}^N \frac{\bar{\epsilon}^E}{\bar{\epsilon}} = \sigma'_{ij}{}^N \cdot \frac{Y}{\bar{\sigma}^N} \quad (G.25)$$

where

$$\sigma'_{ij}{}^N = 2G\epsilon'_{ij} \quad (G.26)$$

and $\bar{\sigma}^N$ is calculated from the $\sigma'_{ij}{}^N$ using equations of the same form as Eq. (G.4). With the aid of Eqs. (G.16) and (G.22), the stresses may also be evaluated as

$$\sigma'_{ij} = \sigma'_{ij}{}^N \cdot \frac{M + 3G \frac{\bar{\sigma}^N}{\bar{\sigma}^D}}{M + 3G} \quad (G.27)$$

Normally in wave propagation calculations, the strains are computed at each step but not stored. From the strains, new stresses are computed and stored until the next cycle. Equations (G.25) and (G.26) are the only ones needed for perfect plasticity model calculations. For linear work hardening, Eqs. (G.25) and (G.27) are required and a yield value must be stored for each cell.

The individual plastic strain increments are obtained by inverting Eq. G.13 and using the deviator stress from Eq. G.25 or G.26.

$$d\epsilon_{ij}^P = \frac{3d\bar{\epsilon}^P}{2\bar{\sigma}} \sigma'_{ij}$$

Note that the plastic strain increments are not necessarily proportional to the applied strain increments.

The foregoing relations are simplified for the cases of one-dimensional flow in Appendix F.

The preceding equations are valid whenever the change in direction of $\vec{\sigma}$ is small in an increment. This restriction arises because $d\vec{\epsilon}$ is calculated as if it were proportional to and in the direction of the final values of $\vec{\sigma}$ in the increment. In a more accurate calculation $d\vec{\epsilon}^P$ would be directed toward an average $\vec{\sigma}$ during the increment. However, for most calculations with solids this latter refinement is not necessary.

Strain-Rate Effects

The linear-viscous model for strain-rate effects is used here. Initially, the analysis is developed for the case of pure shear and then transformed to the multidimensional case. In terms of shear stress τ , the stress-strain relation is

$$\frac{\partial \tau}{\partial t} = G \frac{\partial \gamma}{\partial t} - \frac{\tau - Y_{\tau}}{T} \quad (G.28)$$

where T is the time constant, γ is the shear strain, and Y_{τ} is the yield stress in shear. With this form, a very rapid loading proceeds elastically, because the first two terms dominate. For gradual loading, τ must remain near Y_{τ} in the plastic range, so the behavior is like rate-independent plastic flow. At intermediate rates, an initial overshoot of τ above Y_{τ} occurs, and then τ gradually reduces to Y_{τ} . For computational purposes, we consider a short time interval, Δt , over which the strain rate is known and constant. The shear stress at any time, t , in the interval is obtained by integrating Eq. (G.28)

$$\tau = \tau_1 e^{-t/T} + (G\dot{\gamma}T + Y_{\tau})(1 - e^{-t/T}) \quad (G.29)$$

where τ_1 is the shear stress at the beginning of the interval.

The analogous calculation is performed for a multidimensional flow by casting Eq. (G.28) in the following form.

$$\frac{d\sigma'_{ij}}{dt} = 3G \frac{d\epsilon'_{ij}}{dt} - \frac{\sigma'_{ij} - \frac{2}{3}Y \frac{d\epsilon^P_{ij}}{d\bar{\epsilon}^P}}{T} \quad (G.30)$$

As in Eq. (G.28), the first term on the right-hand side is the elastic relation. The second term represents the excess stress above the static yield value; this excess is driving the rate process. The static yield stress in the ij direction is obtained from Eq. (G.13) as $2Yd\epsilon^P_{ij}/3d\bar{\epsilon}^P$. Equation (G.30) is then integrated, holding all strain rates constant in the interval:

$$\sigma'_{ij} = \sigma'_{ijo} + \left[-\sigma'_{ijo} + \frac{2Yd\epsilon^P_{ij}}{3d\bar{\epsilon}^P} + 2GT \frac{d\epsilon'_{ij}}{dt} \right] \left[1 - e^{-(t - t_o)/T} \right] \quad (G.31)$$

where σ'_{ijo} and t_o are deviator stress and time at the beginning of the interval. Equation (G.23) can be evaluated for a time step if an estimate of $d\epsilon^P_{ij}/d\bar{\epsilon}^P$ can be obtained from Eq. (G.13). In our calculations, the first estimate is

$$\frac{2d\epsilon^P_{ij}}{3d\bar{\epsilon}^P} \doteq \frac{\sigma'^N_{ij}}{\bar{\sigma}^N} \quad (G.32)$$

where the stress quantities are computed elastically. Subsequent estimates are based on the results of the evaluation of σ'_{ij} from Eq. (G.31). Equation (G.32) represents a good approximation when only small changes are evident in the relative importance of the components of the stress tensor, that is, when only small changes occur in the principal stress directions.

Appendix H

INSERTION PROCEDURE

As new material models are generated, they can be added to SRI PUFF for performing wave propagation calculations. This appendix describes the procedure for inserting material model subroutines.

A wave propagation code normally has four main categories of operations: reading the input data, initializing a finite difference grid, performing calculations for each time increment at each grid point, and printing the computed information. A material model subroutine may be involved in all or some of these operations. Call statements must be provided in SRI PUFF at appropriate locations to accomplish these tasks. Also the new subroutine should be provided with separate sections for each operation and an indicator to show which operation to perform. For example, in SHEAR2 the formal parameter NCALL indicates the operation required, as follows:

NCALL = 0 Initialize the routine and read data for one material
1 Read data for one material
2 Calculate stresses and damage
3 Calculate stresses and damage, and print results
4 Print results only.

The calls for NCALL = 0 and 1 are in GENRAT. There, NCALL is LSUB(15), a parameter that is initially zero. After the first call, LSUB(15) is set to 1. For NCALL = 2 and 3, the call statement is in HSTRESS. Other calling strategies are also possible. For example, BFRAC is initialized on the first call from HSTRESS; there are no other calls. EXPLODE is called from GENRAT to read data and then called for each cell during the layout to initialize array variables. During propagation calculations, EXPLODE is also called by HSTRESS.

At the point of insertion of the call statement, four elements are provided.

- (1) The appropriate branching statements are needed to switch to the new model when it is required. For SHEAR2, it was decided to treat the model as a fracture routine and designate it by $NFR(M) = 3$. Then the available branching statements in GENRAT and HSTRESS were amplified to include one more branch.
- (2) Variables must be initialized, calibrated, or given sign changes just preceding the call statement.
- (3) The call statement is provided.
- (4) Some variables may need to be reset following the calculations in the routine. Then a jump is provided to the appropriate section of HSTRESS or GENRAT to continue the calculation.

Items (2), (3), and (4) are discussed further below following introduction of a call statement.

A sample call statement for SHEAR2 is listed here as it appears in HSTRESS, but the same call can be used in GENRAT.

CALL SHEAR2 (NCALL, IN, M, J, J, H(J,3), SX, SY, SZ, TXY, PHL(J), COM(L), DH, DOLD, DT, EH, EOLD, COM(L+1), EMELT(M,1), COM(L+2), EX, EY, EZ, EXY, F, YHL(J), COM(L+3), ROT, DROT, ESC, COM(L+4)). Because SHEAR2 represents a fairly complex case, this call statement will be discussed in detail.

The initialization of NCALL for use in GENRAT was described above. For HSTRESS, NCALL is initialized just before the call statement. NCALL is set to 2 normally, but it is set to 3 on cycles when an EDIT will occur. The parameter IN is the file containing input data. Normally IN is 5 but may be reset in GENRAT to 4 for a special data file. The coordinate number J appears twice because the SHEAR2 subroutine is also used in two-dimensional calculations where two indices are needed. The stress components SX, SY, SZ, TXY are positive in tension in HSTRESS, although the array quantities SHL, PHL, SDT, and SDH are positive in compression. If necessary, sign and magnitude changes can be made in the stresses just preceding the call statement. The strain quantities EX, EY, EZ, EXY are also positive in tension. In SHEAR2 most of the material properties are

inserted in two large arrays: ESC and TSR. The ESC array, listed in Table H.1, is for the usual equation of state parameters, whereas TSR is for the special fracture parameters. The rotation parameter ROT is zeroed before the call are stored in the COM array, beginning at location $L = LVAR(J)$. The use of COM and LVAR is described in Appendix C.

Following insertion of a new material model, it is a good plan to run a simple problem with frequent EDITs to determine whether the routine is performing satisfactorily.

Table H.1

MATERIAL PARAMETER ARRAY ESC

No.	Definition
1	Original density, g/cm^3
2	Bulk modulus (C), dyn/cm^2
3,4	D and S in the pressure equation: $P = C\mu + D\mu^2 + S\mu^3$ where $\mu = \text{density/ESC (M,1)} - 1$
5	Shear modulus (G), dyn/cm^2
6	YADD, work hardening modulus, $\text{dyn/cm}^2/(\text{g/cm}^3)$
7	Initial solid density, g/cm^3
9	Grüneisen ratio
<u>10</u>	Initial yield strength, dyn/cm^2
Notes	

Array dimension is ESC (6,20) with the first subscript for material number and the second for property number (the number listed above). Thus ESC (M,5) is the shear modulus for material M. The ESC array is initialized in GENRAT at the end of the materials loop.

Appendix I

LISTING OF SRI PUFF 8

The following listing contains all the routines currently used with PUFF. The main program is given first, with all the subroutines following in alphabetical order. Included are SRI PUFF8, BANDRLX, BAUSCHI, BECOM, BEMOD, BFRACT, CAP1, DEPOS, DFRACT, EDIT, EOSTAB, EPLAS, EQST, EQSTPF, ESA, EXPLODE, EXTRA, FMELT, GENRAT, GRAY, HAFSTEP, HDATA, HSTRESS, HYDRO, HYPO, PEST, POREQST, PORHOLT, PRESCR, REBAR, REDR, RELAX, REZONE, SCATTO, SCRIBE, SHEAR2, SIGMAT, SSCALH, STORR, STRES2, and TSQE. A brief description of each subroutine and references for the material models are given in SECTION 2.

SUBROUTINE SRIPUFF

```

PROGRAM SRIPUFF (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE3=2500, SRIPUFF2
1  TAPE4,TAPE7,TAPE2=400) SRIPUFF3
C SRIPUFF4
C SRIPUFF5
C SRIPUFF6
C SRIPUFF7
C SRIPUFF8
C SRIPUFF9
C SRIPUFF10
C SRIPUFF11
C SRIPUFF12
C SRIPUFF13
C SRIPUFF14
C SRIPUFF15
C SRIPUFF16
C SRIPUFF17
C SRIPUFF18
C SRIPUFF19
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C SRIPUFF21
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C SRIPUFF25
C SRIPUFF26
C SRIPUFF27
C SRIPUFF28
C SRIPUFF29
C SRIPUFF30
C SRIPUFF31
C SRIPUFF32
C SRIPUFF33
C SRIPUFF34
C SRIPUFF35
C SRIPUFF36
C SRIPUFF37
C SRIPUFF38
C SRIPUFF39
C SRIPUFF40
C SRIPUFF41
C SRIPUFF42
C SRIPUFF43
C SRIPUFF44
C SRIPUFF45
C SRIPUFF46
C SRIPUFF47

      SRI PUFF 8, VERSION OF OCTOBER 1975
      WRITTEN AT STANFORD RESEARCH INSTITUTE BY L. SEAMAN
      CODE HANDLES FRACTURING, EXPLOSIVES, POROUS MATERIALS,
      BAUSCHINGER EFFECT, AND STRESS RELAXATION IN RADIATION OR
      IMPACT PROBLEMS.

      MAIN PROGRAM * * *
      * CALLS GENRAT TO READ DATA AND INITIALIZE ARRAYS
      * CALLS HYDRO FOR EACH CYCLE OF CALCULATIONS
      * SETS TIME STEP
      * CALLS EDIT AND REZONE AS REQUIRED
      * CALLS SCRIBE TO STORE RESULTS AND FOR TERMINAL PRINTOUT

      INTEGER H,POROUS,PRESS,RINTER,SOLID,SPALL
      REAL MATL,NEM,NET,NEMH,NETH
      MISCELLANEOUS
      COMMON AZERO(1),CEF,CKS,DAVG,DELTIM,DISCPT(10),DOLD,DRHO,DTMAX,
1  DTMIN,DTN,DTNH,DU,DX,EOLD,F,FAC,FIRST,J,JCYCS,JINIT,
2  JFIN,JREZON(15),JSMAX,JSTAR,JTS,LSUB(30),M,MAXPR(30),N,NCYCS,
3  NEDIT,NPERN,NR,NREZON,NSCRB(6),NSEPRAT,NSPALL,NTEDT,
4  NTEX,NTR(15),POLD,P6(20),R(30),RLAST,SLAST,SMAX,TEDIT(50),
5  TF,TIME,TJ,TREZON,TS,T6(20),ULAST,UOLD,UZERO,XLAST,XNOW,XOLD
1  ,XJEDIT(20)
      HALFSTEP VALUES
      COMMON DH,DHLAST,DUH,EH,PH,RH,RHLAST,SH,SHLAST,UH,UHLAST,XH,XHLAST
1  ,NEMH,NETH
      CONDITION INDICATORS
      COMMON INF,LINTER,MIRROR,NORMAL,POROUS,PRESS,RINTER,SOLID,SPALL
      CELL LAYOUT
      COMMON DX(30),JBND(30),JMAT(30),NAUTO,MATL(6,2),NLAYER,NMTRLS,
1  THK(30)
      COORDINATE ARRAYS
      COMMON/COORD/X(200),X0(200),CHL(200),DHL(200),DPDD(200),DPDE(200),COORDC03
1  EHL(200),H(200,3),NEM(200),NET(200),PHL(200),RHL(200),SDT(200),
2  SHL(200),T(200),U(200),YHL(200),ZHL(200)
      COMMON /RAD/ SSTOP(5),START(5),SDURM,SSTOPM,NSPEC,SSJ,JSS,IPL0T(4)
1  ,XMAX(4),XMIN(4),YMAX(4),YMIN(4),IA(7),ITITLE(24),NARZ,TARZ
      CALL SECOND(FIRST) $ XIN=FIRST
      CALL GENRAT
      QUICK STOP FOR PROBLEM LAYOUT ONLY
      IF (JCYCS .LE. 0) GO TO 100
      NPERN=MAX0(NPERN,1)
      CN=NCYCS=NPERN $ IT=MIN0(0,NTEDT-1) $ NT=0 $ SF=0.8
      N=NR=1
      CALCULATE AND STORE HYDRODYNAMIC DATA
200 CALL HYDRO
      XINL=XIN $ CALL SECOND(XIN) $ DELTIM=XIN-XINL
      PERIODIC EDITS, PRINTS
      IF (MOD(N, 25) .EQ. 0) 205,210
205 CALTIM=XIN-FIRST
      WRITE(6,889)N,JSTAR,TIME,CALTIM,JTS,DTNH,SMAX,JSMAX
210 IF (MOD(N,NEDIT) .EQ. 0 .AND. N .NE. JCYCS) CALL EDIT
      IF (LSUB(7) .EQ. 1) GO TO 390
      STORE DATA IN BUFFER
      CALL STORR
      JTS=MOD(JTS,1000)
      STOP PARAMETERS
      IF (TIME .LT. TS) 304,400
304 IF (N .EQ. JCYCS) 400,305

```

SUBROUTINE SRIPUFF (Concluded)

305	IF (X(JSMAX) - CKS) 500,400,400	SRIPUF48
C		SRIPUF49
C	ERROR FINISH	SRIPUF50
390	N=N-I	SRIPUF51
400	WRITE (6,84I)	SRIPUF52
	WRITE (6,840) N,JCYCS,TIME,TS,X(JSMAX),CKS,LSUB(7),DTNH	SRIPUF53
	LSUB(7)=1 \$ CALL EDIT \$ CALL STORR \$ CALL SCRIBE	SRIPUF54
C	PROGRAM HALTS ON COMPLETION OF ALL DATA DECKS	SRIPUF55
	GO TO 100	SRIPUF56
C		SRIPUF57
C	TIME STEP CALCULATION	SRIPUF58
500	DTNH=AMINI(SF*DTMIN,AMAX1(1.2*DTNH,.035*SF*DTMIN))	SRIPUF59
	IF (NSPEC .EQ. 0 .OR. SDURM .EQ. 1.) GO TO 530	SRIPUF60
	SOURM=1.	SRIPUF61
	DO 510 NS=1,NSPEC	SRIPUF62
	IF (TIME+DTNH .GT. START(NS) .AND. TIME .LT. SSTOP(NS)) DTNH =	SRIPUF63
I	AMIN1(DTNH,AMAX1(START(NS)-TIME,0.))+0.03*(SSTOP(NS)-START(NS)))	SRIPUF64
	IF (TIME-.5*DTN .LT. SSTOP(NS)) SDURM=0.	SRIPUF65
510	CONTINUE	SRIPUF66
530	CN=NCYCS=NPERN	SRIPUF67
C		SRIPUF68
C	PERIODIC REZONE	SRIPUF69
	IF (NREZON .GE. 0) GO TO 534	SRIPUF70
	IF (TIME .LT. TREZON) GO TO 534	SRIPUF71
	IF (OTNH .GE. DTMAX) GO TO 534	SRIPUF72
	ENARZ=NARZ \$ ENR=NR	SRIPUF73
	IF (ENARZ+TARZ .NE. 0. .AND. ENR .GT. ENARZ .AND. TIME .GT. TARZ) GO	SRIPUF74
1	TO 534	SRIPUF75
	IF (NR .EQ. 1) JCR=N	SRIPUF76
	IF (N .LT. JCR+(NR-1)*IABS(NREZON)) GO TO 534	SRIPUF77
	CALL EDIT	SRIPUF78
	CALL REZONE \$ NR=NR+1	SRIPUF79
C		SRIPUF80
C	TIME EDIT AND REZONE CALL	SRIPUF81
534	IF (IT) 560,550,535	SRIPUF82
535	CALL EDIT \$NT=NT+I	SRIPUF83
	IF (NREZON .LE. 0) GO TO 538	SRIPUF84
	IF (NT .EQ. NTR(NR)) 537,538	SRIPUF85
537	CALL REZONE \$ NR=NR+1	SRIPUF86
538	IF (NT .EQ. NTEDT) 540,545	SRIPUF87
540	IT=-1 \$ GO TO 560	SRIPUF88
545	IT=0	SRIPUF89
550	IF (TIME+CN*DTNH .LT. TEDIT(NT+1)) 560,555	SRIPUF90
555	NCYCS=(TEDIT(NT+1)-TIME)/OTNH+1 \$ CN=NCYCS	SRIPUF91
	DTNH=AMAX1((TEDIT(NT+1)-TIME)/CN,0.1*DTNH) \$ IT=1	SRIPUF92
560	N=N+1	SRIPUF93
	IF (DTNH .GE. 1.E-14) 200,565	SRIPUF94
565	N=N-1 \$ GO TO 400	SRIPUF95
C		SRIPUF96
840	FORMAT(/ 5H N =I4,9H, JCYCS =I4, 8H, TIME =1PE10.3,6H, TS =	SRIPUF97
	1 E10.3,12H, X(JSMAX) =,E10.3, 7H, CKS =,E10.3,10H, LSUB(7)=13,	SRIPUF98
	2 ,8H, OTNH =1PE10.3)	SRIPUF99
841	FORMAT (/4X,28H**** CRITERION FOR STOP ****)	SRIPU100
889	FORMAT (5H N=I5,8H, JSTAR=I4,7H, TIME=1PE10.3,12H, CALC TIME=	SRIPU101
	1 F10.3,11H SECS, JTS=I4,7H DTNH=1PE10.3,7H SMAX=1PE10.3,	SRIPU102
	2 8H JSMAX=I4/)	SRIPU103
	END	SRIPU104

SUBROUTINE BANDRLX

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SUBROUTINE BANDRLX(ICON,SD,Y1,ORO,COEF,N,J,M,NM,NT,DT,TSR,MUM,
1  YO,INSR)
C
C CALLED BY *HSTRESS* TO COMPUTE OEVIATOR STRESS FOR BAND AND
C GILMAN RELAXATION MODELS, NDS = 2 AND 3.
C FOLLOWING TABLE GIVES CORRESPONDENCE OF COMMON, BANDRLX VARIABLES
C COMMON  NSR  TSR(1)  (2)  (3)  (4)  (5)  (6)  NEM  NET
C BANO      2      T1   T2   BEE  VM   GEE  EPS  NM   NT
C GILMAN     3      CEE  PHI  BEE  VM   BNM0  -   NM   GAM
C NOTE. MEOW=MUM, YAO=YADO, INSR=NSR
C NEM AND NET ARE MORILE AND TOTAL DISLOCATIONS
C GAM IS PLASTIC SHEAR STRAIN
C JK IS A PATH INDICATOR
C INPUT - ALL FORMAL PARAMETERS.
C OUTPUT - SO, ICON, NM, NT, YNOT.
C
REAL NM,NT,NMO,NT0,MEOW,MUM
DIMENSION TSR(6,30)
YAO=0.6667*YD
YNOT=0.6667*Y1
C
T1=TSR(M,15)  $  T2=TSR(M,16)  $  BEE=TSR(M,17)
VM=TSR(M,18)  $  GEE=TSR(M,19)  $  EPS=TSR(M,20)
MEOW=2.*MUM
C
ICOR = ICON  $  YNOT0=YNOT
NT0 = NT  $  NMO = NM  $  SOO = SO
NIT=4
L=0  $  ENT=FLOAT(NIT)  $  IT=0
SIGNN = SIGN(1.,SOO)
IF (ICON .EQ. 2)2,10
C INITIAL CONOITION$ INSIDE ELASTIC ZONE
2 SD=SDO+COEF
IF (ABS(SD).GT.YNOT)5,66
C DEVIATOR LEAVES ELASTIC ZONE. CALCULATE RELAXATION
5 L = 1
S = .5*(ABS(SDO+COEF)-YNOT)
DELT = (SD-SIGN(YNOT,COEF))/(SO-SDO)*DT
SIGNN= SIGN(1.,COEF)
ENT=1.  $  SD=SDO
GO TO 40
C INITIAL CONDITION OUTSIDE OF ELASTIC ZONE
10 L=2
IT=IT+1  $SDI=SO+COEF/(2.*ENT)
S=ABS(SOI)-YNOT  $  DELT=OT/ENT
IF(S.LE.0.)18,11
C AVERAGE OEVIATOR REMAINS OUTSIOE ELASTIC ZONE. CALCULATE RELAXATI
11 L=3
IF(SIGNN.EQ.SIGN(1.,SDI))40,17
13 IF(ABS(SD).GT.YNOT)14,16
14 L=4
IF(SIGN(1.,SD).EQ.SIGNN)15,16
C OEVIATOR REMAINS OUTSIOE ELASTIC ZONE AFTER RELAXATION
15 L=5
IF(IT.EQ.NIT) 62,10
16 SO=SDI-COEF/(2.*ENT)
17 L=6
C DEVIATOR REENTERS ELASTIC ZONE. RECALCULATE RELAXATION
18 S = .5*(ABS(SO)-YNOT)  $YSTAR = SIGN(YNOT,SDO)
DELT=(YSTAR-SO)/COEF*DT
GO TO 40
19 SD=SD+COEF/ENT*FLOAT(NIT-IT)
IF (ABS(SD).GT.YNOT)21,20
20 ICON = 2
GO TO 66
C DEVIATOR CROSSES OVER TO OPPOSITE SIDE OF ELASTIC ZONE. RECALCULATE

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SUBROUTINE BANDRLX (Concluded)

21	IF (SIGN(1.,SD).EQ.SIGN) GO TO 62	BANDRL69
	SIGN = -SIGN \$ L=7	BANDRL70
	DELT = (SD+YSTAR)/COEF*OT	BANDRL71
	S = .5*(ABS(SD)-YNOT)	BANDRL72
	SD=SD-COEF \$ ENT=1.	BANDRL73
40	ARG=4.*BEE/3./S	BANDRL74
	IF (ARG.GT.20)42,43	BANDRL75
42	XPO = 0. \$ GO TO 45	BANDRL76
43	XPO = EXP(-ARG)	BANDRL77
45	GO TO (96,51,52) INSR	BANDRL78
C	PERFORM RELAXATION CALCULATIONS - BAND MODEL	BANDRL79
51	TP=NT	BANDRL80
	NT=NT+(EPS*GEE*S*(NT-NM)-1./T2*NM*XPO)*DELT	BANDRL81
	NM=NM+(GEE*S*(TP-NM)-(1./T1+1./T2)*NM*XPO)*DELT	BANDRL82
	GO TO 54	BANDRL83
C	PERFORM RELAXATION CALCULATIONS - GILMAN MODEL	BANDRL84
52	CEE=T1 \$ PHI=T2 \$ BNMO=GEE \$ GAM=GAM0=NT	BANDRL85
	NM=BNMO*(1.+CEE*GAM)*EXP(-PHI*GAM)	BANDRL86
54	SD=SD+COEF/ENT-1.333*MUM*NM*VM*XPO*DELT*SIGN	BANDRL87
55	GO TO (60,19,13,19,96,19,60)L	BANDRL88
60	ICON = 2-IFIX(SIGN(1.,SD))	BANDRL89
C	RECALCULATE YIELD STRENGTH IN CASES OF STRAIN HARDENING	BANDRL90
62	YNOT = AMIN1(ABS(SD),YNOT+YAO*ABS(DRO))	BANDRL91
	IF (YNOT.EQ.ABS(SD)) 64,66	BANDRL92
64	ICON=2 \$ L= L+50	BANDRL93
66	CONTINUE	BANDRL94
	GO TO (96,90,78) INSR	BANDRL95
78	OGAM = ABS(SD0+COEF-SD)/2.667/MUM	BANDRL96
	NT=GAM=GAM+DGAM	BANDRL97
	Y1 = 1.5 *YNOT	BANDRL98
90	RETURN	BANDRL99
96	WRITE (6,199) INSR,L	BANDR100
	Y1 = 1.5 *YNOT	BANDR101
	RETURN	BANDR102
199	FORMAT (25H ERROR IN BANDRLX,INSR = 15,5H, L = 15)	BANDR103
	END	BANDR104

SUBROUTINE BAUSCHI

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SUBROUTINE BAUSCHI(INO,SD,OS,YC,YHL,EP,EPM,HT,HC,XP,G)      BAUSCHI2
C                                                              BAUSCHI3
C      ROUTINE PROVIDES A BAUSCHINGER EFFECT WHEN DEVIATOR CHANGES BAUSCHI4
C      SIGN. FUNCTION HAS THE FORM  $(S/S_0)^{2N} = EP/EPM$  BAUSCHI5
C      INO=H(J,3), 2 = COMPRESSION, 0 = TENSION BAUSCHI6
C      SD =DEVIATOR STRESS, INPUT AS SDO, OUTPUT AS SDH OR SDJ BAUSCHI7
C      DS = CHANGE IN DEVIATOR, SD=SD+DS, INPUT AS ELASTIC CHANGE BAUSCHI8
C      YC =NEM, CURRENT YIELD, SET TO ZERO WHEN SIGN OF DEVIATOR CHANGES BAUSCHI9
C      Y =YHL, YIELD (USED AT 2/3RDS ACTUAL VALUE) BAUSCHI10
C      EP =NET(), PLASTIC STRAIN, RESET TO ZERO WHEN OEV. CHANGES SIGN BAUSCHI11
C      EPM=TSR(1), PLASTIC STRAIN AT WHICH BAUSCHINGER EFFECT CEASES BAUSCHI12
C      HT =TSR(2), WORK HARDENING MODULUS IN TENSION BAUSCHI13
C      HC =TSR(3), WORK HARDENING MODULUS IN COMPRESSION BAUSCHI14
C      XP =TSR(4)=1/N IN OEFINING EQUATION, EXPONENT BAUSCHI15
C      M =4/3RDS ELASTIC SHEAR MODULUS, M=MU + EXMAT(M,1) * (D/RHO-1) BAUSCHI16
C                                                              BAUSCHI17
C      REAL M BAUSCHI18
C      Y = 0.6667 *YHL BAUSCHI19
C      M = 1.333 * G BAUSCHI20
C      IF (DS*SD .GE. 0.) GO TO 100 BAUSCHI21
C***** BEGIN ROUTE FOR CHANGE IN DIRECTION OF LOADING *****BAUSCHI22
C      IF (SO*(SO+OS) .GE. 0.) GO TO 400 BAUSCHI23
C      STRESS HAS CHANGED SIGN. PREPARE FOR BAUSCHINGER EFFECT BAUSCHI24
C      IF (ABS(EP) .LE. 0.) GO TO 100 BAUSCHI25
C      YC=EP=0. $ INO=1+SIGN(1.,SD+DS) $ GO TO 300 BAUSCHI26
C***** BEGIN ROUTE FOR CONTINUED LOADING IN SAME DIRECTION *****BAUSCHI27
C      BRANCH TO ELASTIC PATH IF YIELD IS NOT EXCEEDED BAUSCHI28
C      100 IF (ABS(SD+DS) .LT. YC) GO TO 400 BAUSCHI29
C      BRANCH TO BAUSCHINGER PATH IF PLASTIC STRAIN IS LESS THAN EPM BAUSCHI30
C      IF (YC .LT. Y .AND. ABS(EP) .LT. EPM) GO TO 300 BAUSCHI31
C      BAUSCHI32
C***** LINEAR WORK HARDENING PATHS *****BAUSCHI33
C      COMPRESSION BAUSCHI34
C      200 IF (SD .LT. 0.) GO TO 220 BAUSCHI35
C      SD=YC=Y=SD+(OS*HC+M*(Y-SD))/(HC+M) BAUSCHI36
C      DEP=(SD+OS-YC)/(M+H) $ EP=EP+DEP BAUSCHI37
C      YHL = 1.5 * Y BAUSCHI38
C      RETURN BAUSCHI39
C      LINEAR WORK HARDENING IN TENSION BAUSCHI40
C      220 SO=SD+(DS*HT-M*(Y+SD))/(HT+M) BAUSCHI41
C      YC=Y=-SO BAUSCHI42
C      DEP=(SD+DS-YC)/(M+H) $ EP=EP+DEP BAUSCHI43
C      YHL = 1.5 * Y BAUSCHI44
C      RETURN BAUSCHI45
C      BAUSCHI46
C***** BAUSCHINGER - NONLINEAR WORK HARDENING - PATH *****BAUSCHI47
C      SET INITIAL PLASTIC MODULUS AND WORK HARDENING MODULI BAUSCHI48
C      300 IF (ABS(EP) .LT. 1.E-4) GO TO 310 BAUSCHI49
C      HO=AMIN1(YC*XP/ABS(EP),1.E14) BAUSCHI50
C      DEPA=ABS((SD+DS-SIGN(YC,SD+DS))/(HO+M)) BAUSCHI51
C      HO=0.5*(HO+(YC+HO*DEPA)*XP/(ABS(EP)+DEPA)) BAUSCHI52
C      GO TO 315 BAUSCHI53
C      310 HO=ABS(SD+DS-SIGN(YC,SD+OS))/(EPM*(ABS(SD+OS)/Y)**(1./XP)-ABS(EP)) BAUSCHI54
C      315 H=HC BAUSCHI55
C      IF (SD+OS .LT. 0.) H=HT BAUSCHI56
C      L=0 BAUSCHI57
C      INITIAL ESTIMATES OF -EP- AND -YC- BAUSCHI58
C      DEP=(SO+OS-SIGN(YC,SD+DS))/(HO+M) BAUSCHI59
C      EPABS=ABS(EP+OEP) BAUSCHI60
C      YC=Y*AMIN1(1.,(EPABS/EPM)**XP)+H*AMIN1(ABS(DEP),AMAX1(0.,EPABS BAUSCHI61
C      1 -EPM)) BAUSCHI62
C      HO=YC*XP/EPABS BAUSCHI63
C      IF (EPABS .GT. EPM) HO=H BAUSCHI64
C      330 DSE=SIGN(YC,DS)-SD BAUSCHI65

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SUBROUTINE BAUSCHI (Concluded)

C	BEGIN ITERATIONS FOR PLASTIC STRAIN AND YIELD	BAUSCH66
	L=L+1	BAUSCH67
	DEP2=DEP	BAUSCH68
	DEP=(DS-DSE+H0*DEP)/(H0+M)	BAUSCH69
	IF (DEP*DEP2 .LT. 0.) DEP=DEP2/3.	BAUSCH70
	EPABS=ABS(EP+DEP)	BAUSCH71
	YC=Y*AMIN1(1.,(EPABS/EPM)**XP)+H*AMIN1(ABS(DEP),AMAX1(0.,EPABS	BAUSCH72
	1 -EPM))	BAUSCH73
	H0=YC*XP/EPABS	BAUSCH74
	IF (EPABS .GT. EPM) H0=H	BAUSCH75
	IF (L .GT. 10) GO TO 350	BAUSCH76
	IF (ABS(SIGN(YC,DS)-SD-DSE) .GT. 1.E6) GO TO 330	BAUSCH77
350	SD=SIGN(YC,DS)	BAUSCH78
	Y=AMAX1(Y,YC)	BAUSCH79
	EP=EP+DEP	BAUSCH80
	YHL = 1.5 * Y	BAUSCH81
	RETURN	BAUSCH82
C		BAUSCH83
C*****	ELASTIC ROUTE	*****BAUSCH84
400	SD=SD+DS	BAUSCH85
	RETURN	BAUSCH86
	END	BAUSCH87

SUBROUTINE BECOM

	SUBROUTINE BECOM(D,SDH,DTNP1,J,N)	RECOM	2
	COMMON /S2/ ALF,CO,EEN,EENP1,EPN,KS,TAUEL,TAUI,TAUN,TAUO,VELS,VMU,ALCOM	ALCOM	2
1	ZAM,ZAMUSV,ZEP,ZEPDSV,ZEPMAXC,ZEPMAXS,ZEPSAVE,ZTAUY,ZTAUVMX	ALCOM	3
	DIMENSION TEMP(30)	BECOM	4
C		BECOM	5
	DATA ALF, HETA, BOB2, BVIOB, CB, CS, EM/	BECOM	6
1	4.E13, 5.2E10, 1.89E11, 3.85E9, 2.E-4, 8.86E5, 6.25/	BECOM	7
	DATA RBVI, SM, SMA, SMB, VO/	BECOM	8
1	28.2, 0.16, 17.0, 2.3E-8, 1.18E8/	BECOM	9
C		RECOM	10
C	*** INITIALIZATION OF FLAGS AND CONSTANTS - BASED UPON THE	BECOM	11
C	STRESS-STRAIN PROPERTIES AT TIME(N). ***	BECOM	12
C		BECOM	13
C	*** KK .EQ. 0 - INITIAL LOADING PHASE	BECOM	14
C	KK .EQ. 1 - UNLOADING OR RELOADING PHASES	BECOM	15
C		BECOM	16
	C1=ZAMUSV	BECOM	17
	ICONV=0	BECOM	18
	ITER=ITH=FT=1.	BECOM	19
	KK=0	BECOM	20
	SIGNT=SIGN(1.,TAUN)	BECOM	21
	IF (ZEPMAXS .GT. 0.) KK=1	BECOM	22
	IF (KK .EQ. 1) GO TO 2	BECOM	23
	SIGNE=SIGN(1.,EEN)	BECOM	24
	STAUO=SIGNE*TAUO	BECOM	25
	STAU=SIGNE*TAUI	BECOM	26
	GO TO 3	BECOM	27
2	STAUO=SIGNT*TAUO	BECOM	28
	STAU=SIGNT*TAUI	BECOM	29
C		BECOM	30
C	*** TRANSFER TO EITHER STATEMENT 90, WHICH BEGINS THE CALCULATION	BECOM	31
C	OF THE PLASTIC STRESS-STRAIN PROPERTIES AT TIME(N+1), OR TO	BECOM	32
C	ONE OF THE SPECIAL CASES DETERMINED BY THE STRESS ROUTINE. ***	BECOM	33
C		BECOM	34
3	KSP1=KS+1	BECOM	35
	GO TO (90,10,20,40,50), KSP1	BECOM	36
C		BECOM	37
C	*** KS .EQ. 1 - INITIAL CROSSING OF YIELD POINT, TAUO. THE	BECOM	38
C	FRACTION OF THE TIME STEP IN THE PLASTIC REGIME IS	BECOM	39
C	CALCULATED. ***	BECOM	40
C		BECOM	41
10	FT=(TAUEL-STAUO)/(TAUEL-TAUN)	BECOM	42
C	RECOMPUTE TAUO, USING UPDATED MODULUS	BECOM	43
	C1=AMIN1(ZAMUSV,AMAX1(ZAM-ALF*ABS(EENP1+FT*VELS),1.))	BECOM	44
	TAUEL=C1*EENP1	BECOM	45
	FT=(TAUEL-STAUO)/(TAUEL-TAUN)	BECOM	46
	TAUN=STAUO	BECOM	47
	ZTAUY=STAUO	BECOM	48
	GO TO 90	BECOM	49
C		BECOM	50
C	*** KS .EQ. 2 - CROSSING FROM POSITIVE TO NEGATIVE TAU OR VICE	BECOM	51
C	VERSA. CALCULATED QUANTITIES ARE THE FRACTION OF THE TIME STEP	BECOM	52
C	IN THE PLASTIC REGIME, THE PLASTIC STRAIN AT THE CROSSING	BECOM	53
C	POINT, AND THE CUMULATIVE TOTAL OF THE PLASTIC STRAIN. ***	BECOM	54
C		BECOM	55
20	TAUN=TAUJ=ZTAUY=ZEPDSV=0.	BECOM	56
	STAUO=-STAUO	BECOM	57
	STAU=-STAU	BECOM	58
	SIGNT=-SIGNT	BECOM	59
	FT=AMAX1(0.,AMIN1(1.,-TAUEL/(ZAM*VELS)))	BECOM	60
	EPN=2.*(EENP1+FT*VELS)/3.	BECOM	61
	ZEPMAXS=ZEPMAXS+ABS(ZEPMAXC-EPN)	BECOM	62
	ZEPMAXC=EPN	BECOM	63
	IF (KK.GT. 0) GO TO 30	BECOM	64
	KK=1	BECOM	65
	ZEPSAVE=ABS(ZEPMAXC)	BECOM	66
30	IF (FT .GE..001) GO TO 90	BECOM	67
	EPNP1=EPN	BECOM	68
	GO TO 340	BECOM	69

SUBROUTINE BECOM (Continued)

C		BECOM 70
C	*** KS .EQ. 3 - RELOADING FROM AN ELASTIC POINT TO A PLASTIC	BECOM 71
C	POINT. THE FRACTION OF THE TIME STEP IN THE PLASTIC REGIME	BECOM 72
C	IS CALCULATED. ***	BECOM 73
C		BECOM 74
40	FT=(TAUEL-ZTAUVMX)/(TAUEL-ZTAUY)	BECOM 75
C	RECOMPUTE TAUEL, USING UPDATED MODULUS	BECOM 76
C	C1=AMIN1(ZAMUSV,AMAX1(ZAM-ALF*ABS(EENP1+FT*VELS),1.))	BECOM 77
C	TAUEL=C1*(EENP1-1.5*EPN)	BECOM 78
C	FT=(TAUEL-ZTAUVMX)/(TAUEL-ZTAUY)	BECOM 79
C	ZTAUY=TAUN-ZTAUVMX	BECOM 80
C	GO TO 90	BECOM 81
C		BECOM 82
C	*** KS .EQ. 4 - FIRST ELASTICALLY CALCULATED POINT IN UNLOADING	BECOM 83
C	PHASE. THE TAU AND TAU Y VERSUS STRAIN CURVES CROSS BEFORE	BECOM 84
C	TIME(N+1). ***	BECOM 85
C		BECOM 86
50	IF (KK .GT. 0) GO TO 54	BECOM 87
C		BECOM 88
C	*** UNLOADING FROM INITIAL LOADING PHASE ***	BECOM 89
C		BECOM 90
C	PLASTIC STRAIN IN FIRST PART OF TIME STEP IS FROM	BECOM 91
C	EPDOT = 4/3*PHI*PSI/(PHI+PSI) = A	BECOM 92
C	DTAU=TAUN-ZTAUY	BECOM 93
C	A=0.	BECOM 94
C	IF (ABS(DTAU) .LT. 1.E7) GO TO 52	BECOM 95
C	EPTOT=ABS(ZEPMAXC-EPN)	BECOM 96
C	PHI=SIGNT*AMAX1(1.E-6,AMIN1(1.E6,ABS(DTAU/(VO+BETA*EPTOT**2))))**	BECOM 97
1	EM	BECOM 98
C	CALL BEMOD(KK,J,SIGNT,EPN,ANM)	BECOM 99
C	A=1.333/(EM+1.)/(1./PHI +BOB2/ANM*(1./DTAU+1./(TAUN+ZTAUY)	BECOM100
1	+0.25*(TAUN+ZTAUY)/BVI0B**2))	BECOM101
52	TAUY1=STAU0*SQRT(1.+CO*ABS(ZEPMAXC-EPN-A*DTNP1))	BECOM102
C	FT=DTAU/(TAUY1-ZTAUY+C1*(VELS+1.5*A*DTNP1))	BECOM103
C	FT=AMAX1(0.,AMIN1(1.,FT))	BECOM104
C	EC=EEN-FT*VELS	BECOM105
C	EPNP1=EPN+A*DTNP1*FT	BECOM106
C	ZTAUVMX=STAU0*SQRT(1.+CO*ABS(ZEPMAXC-EPNP1))	BECOM107
C	GO TO 56	BECOM108
C		BECOM109
C	*** UNLOADING FROM A LOADING PHASE OTHER THAN THE INIT. LOADING	BECOM110
C		BECOM111
54	DTAU=TAUN-ZTAUY	BECOM112
C	A=0.	BECOM113
C	IF (ABS(DTAU) .LT. 1.E7) GO TO 55	BECOM114
C	EPTOT=ABS(ZEPMAXC-EPN)	BECOM115
C	PHI=SIGNT*AMAX1(1.E-6,AMIN1(1.E6,ABS(DTAU/(VO+BETA*EPTOT**2))))**	BECOM116
1	EM	BECOM117
C	CALL BEMOD(KK,J,SIGNT,EPN,ANM)	BECOM118
C	A=1.333/(EM+1.)/(1./PHI +BOB2/ANM*(1./DTAU+1./(TAUN+ZTAUY)	BECOM119
1	+0.25*(TAUN+ZTAUY)/BVI0B**2))	BECOM120
55	TAUY1=STAU1*(1.-EXP(-SMA*SQRT(ABS(ZEPMAXC-EPN-A*DTNP1))))	BECOM121
C	FT=DTAU/(TAUY1-ZTAUY+C1*(VELS+1.5*A*DTNP1))	BECOM122
C	FT=AMAX1(0.,AMIN1(1.,FT))	BECOM123
C	EC=EEN-FT*VELS	BECOM124
C	EPNP1=EPN+A*DTNP1*FT	BECOM125
C	ZTAUVMX=TAUN-C1*(FT*VELS+1.5*(EPNP1-EPN))	BECOM126
C		BECOM127
C	UPDATE OF SHEAR STRESS AT TIME N+1	BECOM128
C		BECOM129
56	ZEPDSV=0.	BECOM130
C	ZTAUY=ZTAUVMX-VELS*C1*(1.-FT)	BECOM131
C	TAUJ=ZTAUY	BECOM132
C	IF (TAUJ*ZTAUVMX .GT. 0.) GO TO 340	BECOM133
C	KS=2	BECOM134
C	ZTAUVMX=0.	BECOM135
C	TAUEL=TAUJ	BECOM136
C	GO TO 20	BECOM137

SUBROUTINE BECOM (Continued)

C	*****	BECOM138
C	*** BEGIN ITERATION LOOP FOR STRESS AND PLASTIC SHEAR STRAIN	BECOM139
C	*****	BECOM140
C	EPNP1=EPN	BECOM141
90	EPTOT=ABS(ZEPMAXC-EPN)	BECOM142
	IF (FT .LT. 0.) GO TO 300	BECOM143
	FTDT=FT*DTNP1	BECOM144
	FTVELS=FT*VELS	BECOM145
C	EPTOT=ABS(ZEPMAXC-EPN-ZEPDSV*FTDT)	BECOM146
200	DTAU=TAUN-ZTAUY	BECOM147
	PHI=SIGNT*AMAX1(1.E-6,AMIN1(1.E6,ABS(DTAU/(VO+BETA* EPTOT**2))))**	BECOM148
	1 EM	BECOM149
	T13=DTAU/BVIOB	BECOM150
	PSI=0.	BECOM151
	IF (ABS(T13) .LT. .01) GO TO 205	BECOM152
	T14=(TAUN+ZTAUY)/BVIOB	BECOM153
	CALL BEMOD(KK,J,SIGNT,EPN,ANM)	BECOM154
	PSI=RBVI/ANM*(T13/(SQRT(T13**2+1.)-1.))+T14/(SQRT(T14**2+1.)-1.))	BECOM155
205	EPDO=1./(PSI+1./PHI)	BECOM156
C	NEXT ESTIMATE OF PLASTIC STRAIN IS BASED ON EPDO	BECOM157
	EPNP1=EPN+EPDO*FTDT	BECOM158
	EPNSUM=EPN	BECOM159
	NTIMES=MAX1(1.,AMIN1(5.,3.*ABS(EPNP1-EPN)/(ABS(EPTOT)+1.E-12)))	BECOM160
	IF (ABS(EPTOT) .LT. 1.E-12) NTIMES=5	BECOM161
	DEPB=DEPA=ZEPDSV*FTDT/NTIMES	BECOM162
	DEPB=DEPA-SIGN(1.E-12,VELS)	BECOM163
	DEPAA=EPDO*FTDT/NTIMES	BECOM164
	DO 280 NNN=1,NTIMES	BECOM165
	ITERT=1	BECOM166
262	EPTOT=ABS(ZEPMAXC-EPNSUM-0.5*DEPB)	BECOM167
	EEC=EPNP1+(1.-(NNN-0.5)/NTIMES)*FTVELS	BECOM168
	C1=AMIN1(ZAMUSV,AMAX1(ZAM-ALF*ABS(EEC),1.))	BECOM169
	TAUJ=C1*(EEC-1.5*(EPNSUM+0.5*DEPB))	BECOM170
	IF (KK .EQ. 0) TAUJJ=STAU0*SQRT(1.+CO*EPTOT)	BECOM171
	IF (KK .EQ. 1) TAUJJ=STAU1*(1.-EXP(-SMA*SQRT(EPTOT)))	BECOM172
	DTAU=TAUJ-TAUJJ	BECOM173
	PHI=SIGNT*AMAX1(1.E-6,AMIN1(1.E6,ABS(DTAU/(VO+BETA*EPTOT**2))))**	BECOM174
	1 EM	BECOM175
	T13=DTAU/BVIOB	BECOM176
	PSI=0. \$ IF (ABS(T13) .LT. .01) GO TO 265	BECOM177
	T14=(TAUJ+TAUJJ)/BVIOB	BECOM178
	CALL BEMOD(KK,J,SIGNT,EPNSUM+0.5*DEPB,ANM)	BECOM179
	PSI=RBVI/ANM*(T13/(SQRT(T13**2+1.)-1.))+T14/(SQRT(T14**2+1.)-1.))	BECOM180
265	EPDJ=1./(PSI+1./PHI)	BECOM181
	DEPB8=EPDJ*FTDT/NTIMES	BECOM182
	DEP=(DEPA*DEPB8-DEPAA*DEPB)/(DEPB8-DEPAA+DEPA-DEPB+1.E-12)	BECOM183
	LOC=265	BECOM184
	EPNP1=EPN+DEP	BECOM185
	IF (ABS(DEP-DEPB8) .LT. 0.02*ABS(DEPB8) .OR. ABS(DEPB-DEPB8)	BECOM186
	1 .LT. 1.E-10) GO TO 275	BECOM187
	IF (ITERT .GE. 20) GO TO 295	BECOM188
	IF (ITERT .EQ. 1) GO TO 267	BECOM189
	IF (ABS(DEPB-DEP) .GT. ABS(DEPA-DEP) .AND. MOD(ITERT,3) .NE. 3)	BECOM190
	1 GO TO 270	BECOM191
	GO TO 268	BECOM192
267	DEP=DEPB8	BECOM193
268	DEPA=DEPB \$ DEPAA=DEPB8	BECOM194
270	ITERT=ITERT+1	BECOM195
	DEPB=DEP	BECOM196
	GO TO 262	BECOM197
275	DEPA=DEPB \$ DEPAA=DEPB8	BECOM198
	EPNSUM=EPNSUM+DEP	BECOM199
	IF (ITERT .EQ. 1 .AND. DEP .EQ. 0.) EPNSUM=EPNSUM+DEPB8	BECOM200
280	CONTINUE	BECOM201
	EPNP1=EPNSUM	BECOM202
	GO TO 300	BECOM203
		BECOM204
		BECOM205

SUBROUTINE BECOM (Concluded)

295	LOC=295	BECOM206
	EPNP1=EPN*EPDU*FTDT	BECOM207
	PRINT 1295, LOC,J,N,EPNP1,DEPA,DEPB,DEPAA,DEPBB,EPN,EPDU,FTDT	BECOM208
1295	FORMAT(* LOC=*I4,* J,N=*2I4,*, EPNP1=*1P9E11.3)	BECOM209
300	CONTINUE	BECOM210
	C1=AMIN1(ZAMUSV,AMAX1(ZAM-ALF*ABS(EENP1),1.))	BECOM211
	TAUJ=C1*(EENP1-1.5*EPNP1)	BECOM212
	EPTOT=ABS(ZEPMAXC-EPNP1)	BECOM213
	IF (KK .EQ. 0) TAUJJ=STAUO*SQRT(1.+CD*EPTOT)	BECOM214
	IF (KK .EQ. 1) TAUJJ=STAUJ*(1.-EXP(-SMA*SQRT(EPTOT)))	BECOM215
C		BECOM216
310	IF (ABS(TAUJ) .GT. ABS(TAUJJ)) GO TO 330	BECOM217
	KS=4	BECOM218
	GO TO 50	BECOM219
C		BECOM220
330	IF (ABS(TAUJJ) .LE. 0.) TAUJJ=SIGN(1.,TAUJ)	BECOM221
	ZTAUJ=TAUJJ	BECOM222
	ZEPDSV=EPDJ	BECOM223
340	SDH=4.*TAUJ/3.	BECOM224
	ZEP=EPNP1	BECOM225
C		BECOM226
	RETURN	BECOM227
C		BECOM228
	END	BECOM229

SUBROUTINE BEMOD

	SUBROUTINE BEMOD(KK,J,SIGNT,EPNPH,ANM,DNMDEP)	BEMOD 2
C		BEMOD 3
	COMMON /S2/ ALF,CO,EEN,EENP1,EPN,KS,TAUEL,TAUI,TAUN,TAUU,VELS,VMU,ALCOM	2
1	ZAM,ZAMUSV,ZEP,ZEPDSV,ZEPMAXC,ZEPMAXS,ZEPSAVE,ZTAUY,ZTAUYSX	ALCOM 3
C		BEMOD 5
	DATA ANMO,C8,ANMI2,A2/2.75E6,1.E12,1.E6,1.E4/	BEMOD 6
C		BEMOD 7
C	*** SUBROUTINE BEMOD CALCULATES THE MOBILE DISLOCATION DENSITY	BEMOD 8
C	AND ITS DERIVATIVE WITH RESPECT TO PLASTIC STRAIN FOR	BEMOD 9
C	BERYLLIUM ***	BEMOD 10
C		BEMOD 11
	IF (KK .GT. 0) GO TO 10	BEMOD 12
C		BEMOD 13
C	*** LOADING PHASE ***	BEMOD 14
C		BEMOD 15
	ANM=ANMO+C8*ABS(ZEPMAXC-EPNPH)**2	BEMOD 16
	RETURN	BEMOD 17
C		BEMOD 18
C	*** UNLOADING OR RELOADING PHASE ***	BEMOD 19
C		BEMOD 20
10	EPB=ZEPMAXS-ABS(ZEPSAVE)+ABS(ZEPMAXC-EPNPH)	BEMOD 21
	ANMS=ANMO+C8*ABS(ZEPSAVE)**2	BEMOD 22
	ANM=ANMI2+(ANMS-ANMI2)*EXP(-A2*EPB**2)	BEMOD 23
	RETURN	BEMOD 24
C		BEMOD 25
	END	BEMOD 26

SUBROUTINE BFRACT

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SUBROUTINE BFRACT(LS,SXXEN,SYEN,STEN,TTYEN,EXX1,EYY1,ETT1,EXY1,
1 P,NM,NT,V0,V0LD,D0,E,EEST,EQSTCM,EQSTGM,ELMU,TSR,Y,YD,F,KS,JS,
2 M,NN,RH0S,DR0T,R0T,FU2D,CL,CN)
C
C NEM -- RELATIVE VOLUME OF CRACKS
C NET -- NUMBER OF CRACKS/UNIT VOLUME
C T1 -- CRACK GROWTH COEFFICIENT, CM2/DYN/SEC
C T2 -- THRESHOLD STRESS FOR GROWTH, DYN/CM2
C T3 -- PARAMETER OF NUCLEATION DISTRIBUTION, CM
C T4 -- NUCLEATION RATE COEFFICIENT
C T5 -- THRESHOLD STRESS FOR NUCLEATION
C T6 -- DENOMINATOR OF EXPONENTIAL STRESS FUNCTION
C T7 -- NOT USED
C T8 -- THRESHOLD STRESS FOR ENTERING BFRACT
C T9 -- SWITCH TO INDICATE WHETHER S OR SDH GOVERNS NUCLEATION
C 0 STRESS GOVERNS
C 1 DEVIATOR STRESS GOVERNS
C T10-- BETA, RATIO OF NO. OF FRAGMENTS TO NO. OF CRACKS
C T11-- GAMMA, RATIO OF FRAGMENT RADIUS TO CRACK RADIUS
C T12-- VALUE OF CRACK VOLUME WHICH DEFINES THRESHOLD OF COALESCENCE
C T13-- TF, WHERE FRAGMENT VOLUME = TF*RF**3
C CN -- CRACK DENSITY, NUMBER/CM3
C CL -- CUBE OF CRACK RADIUS, CM3
C
DIMENSION TSR(6,30),FN(7),CL(1),CN(1),COS2TH(4),SIN2TH(4),CL3(5),
1 FNUC(5),STH(5),INIT(6),VCR(6),VFR(6),VCN(6)
REAL NM,NT
DATA ALF,SMF,NANG/1.0,1.88,5/
IF (LS.GT. 0) GO TO 20
C *****
C I N I T I A L I Z A T I O N
C *****
C *** INITIALIZE GENERAL ARRAYS - COS2TH, SIN2TH, R0T, CN, CL, FNUC
LS=1
DO 5 I=1,6
INIT(I)=0
DO 5 J=1,7
FN(J)=0.
5 CONTINUE
NANG1=NANG-1
FNUC(1)=0.707107/NANG1
FNUC(NANG)=0.292893
COS2TH(1)=1.0
SIN2TH(1)=0.
DO 10 NG=2,NANG1
FNUC(NG)=FNUC(1)
TWOTH=6.2831853*FLOAT(NG-1)/FLOAT(NANG1)
COS2TH(NG)=COS(TWOTH)
SIN2TH(NG)=SIN(TWOTH)
10 CONTINUE
C *** INITIALIZE -TSR- COEFFICIENTS FOR EACH MATERIAL
20 IF (INIT(M).EQ. M) GO TO 25
TSR(M,3)=TSR(M,3)**3
VCR(M)=8.*(1./ELMU+1./(EQSTCM+ELMU/3.))
VFR(M)=6.*TSR(M,13)*TSR(M,10)*TSR(M,11)**3
VCN(M)=-TSR(M,3)*TSR(M,4)
INIT(M)=M
PRINT 1025,M,(TSR(M,I),I=1,14),VCR(M),VFR(M),VCN(M)
1025 FORMAT(* INITIALIZE BFRACT FOR M=*12,* TSR=* 1P7E11.3/4X,1P7E11.3/
1 * VCR,VFR,VCN=*1P3E11.3)
25 CONTINUE
IF(LS.EQ. 3)GO TO 500
C *****
C C O M P U T A T I O N S
C *****
IF (NM.LT. 0.) GO TO 410
IF (NT.EQ. 0.) FU2D=1.
FU0=FU2D
VS0=V0LD*(1.-NM)/FU0/RH0S
VV0=V0LD/RH0S-VS0
DV=DV0=(V0-V0LD)/RH0S
D0LD=RH0S/V0LD
PS0=P/(VS0*FU0*D0LD)
R=R0T $ P0=P
C *** SET VALUES FOR MULTIPLE LOOPS IN CASE OF LARGE STRAIN
C MULTIPLE LOOPS IF STRAIN CORRESPONDS TO A STRESS GREATER THAN

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SUBROUTINE BFRACT (Continued)

C	0.33*TSR(M,5)	BFRACT2	77
	SDH=AMIN1(SXXEN,SYEN,STTEN)	BFRACT2	78
	NLOOP=MAX1(1.,-4.*DV*EQSTCM/VSD/TSR(M,5)+0.5,DTD*20.*TSR(M,1)*(PSD	BFRACT2	79
1	+SDH-TSR(M,2))+0.5)	BFRACT2	80
	NLOOP=MIN0(NLOOP,10)	BFRACT2	81
	PS=(EQSTCM/RHOS+EQSTGM*EEST)/(VSD+DV)-EQSTCM	BFRACT2	82
	IF(PSD.GT.0..AND.PS.GT.0.) NLOOP=1	BFRACT2	83
	DPJ=0.5*(ABS(TSR(M,5))+ABS(PSD))	BFRACT2	84
	NTRY=0	BFRACT2	85
100	DELV=DV/NLOOP	BFRACT2	86
	IF(ABS(DVD).LT.1.E-9) DVD=1.E-9	BFRACT2	87
	EXX=EXX1/NLOOP*DV/DVD	BFRACT2	88
	EYY=EYY1/NLOOP*DV/DVD	BFRACT2	89
	ETT=ETT1/NLOOP*DV/DVD	BFRACT2	90
	EXY=EXY1/NLOOP*DV/DVD	BFRACT2	91
	VH=1./DOLD \$ YT=Y	BFRACT2	92
	DE=(EEST-E)/NLOOP	BFRACT2	93
	E1=E	BFRACT2	94
	TEMP1=1./RHOS+EQSTGM*E/EQSTCM	BFRACT2	95
	DR=DELV/DVD*DRDT	BFRACT2	96
	DT=DELV/DVD*DTD	BFRACT2	97
	A1=3.*TSR(M,1)*DT	BFRACT2	98
C		BFRACT2	99
C ***	BEGIN -DO- LOOP FOR EACH STEP IN STRAIN	BFRACT2	100
	DO 380 NL=1,NLOOP	BFRACT2	101
	VH=VH+DELV	BFRACT2	102
	DH=1./VH	BFRACT2	103
	E1=E1+DE	BFRACT2	104
	TEMPD=TEMP1	BFRACT2	105
	TEMP1=1./RHOS+EQSTGM*E1/EQSTCM	BFRACT2	106
	SDH=AMIN1(SXXEN,SYEN,STTEN)	BFRACT2	107
	VOPD=0.	BFRACT2	108
	DO 120 NA=1,NANG	BFRACT2	109
120	VOPD=VOPD+CN(NA)*CL(NA)	BFRACT2	110
	TAUD=VFR(M)*VOPD	BFRACT2	111
	VOPD=-VCR(M)*VOPD	BFRACT2	112
C	*****	BFRACT2	113
C	***** ESTIMATE SOLID PRESSURE TO BEGIN ITERATIONS *****	BFRACT2	114
C	***** STRAIN BASIS FOR PRESSURE ESTIMATE *****	BFRACT2	115
C	*****	BFRACT2	116
	PS=PG=PN=EQSTCM*(TEMP1/(VSD+DELV)-1.)	BFRACT2	117
	IF (P.LT.0.) GO TO 130	BFRACT2	118
C	CRACK OPENING BASIS FOR PRESSURE ESTIMATE	BFRACT2	119
	PG=PSD+(DELV-TEMP1*(1.-PSD/EQSTCM)+VSD)/(VOPD-1./EQSTCM*TEMP1)	BFRACT2	120
	IF (PG.GT.0.) PG=PSD-(DELV-TEMP1*(1.-PSD/EQSTCM)+VSD)/(TEMP1/	BFRACT2	121
1	EQSTCM)	BFRACT2	122
	GO TO 150	BFRACT2	123
C	NUCLEATION BASIS FOR PRESSURE ESTIMATE	BFRACT2	124
130	IF (DELV.GT.0.) PN=-PSD+2.*TSR(M,5)+2.*TSR(M,6)*ALOG(ABS(DELV/	BFRACT2	125
1	VCR(M)/VCN(M)/DT/PSD))	BFRACT2	126
C	GROWTH, EXPANSION, AND STRAIN BASIS FOR PRESSURE ESTIMATE	BFRACT2	127
	XP=EXP(A1*AMIN1(0.,PSD+SDH-TSR(M,2)))	BFRACT2	128
	PG=PSD+(DELV-VVD*XP+VVD-VSD+TEMPD/TEMP1*VSD)/(VVD*XP*(1./(PSD+SDH)	BFRACT2	129
1	+A1/2.))-VSD*VSD/EQSTCM/TEMP1)	BFRACT2	130
150	PJ=AMAX1(PS,PG,PN)	BFRACT2	131
	DVS=TEMP1/(1.+PJ/EQSTCM)-VSD	BFRACT2	132
	COSR=COS(2.*R)	BFRACT2	133
	SINR=SIN(2.*R)	BFRACT2	134
C ***	COMPUTE STRESSES AT TIME(N-1) FOR EACH ANGULAR GROUP	BFRACT2	135
	STH(NANG)=STTEN+PSD	BFRACT2	136
	DO 170 NA=1,NANG1	BFRACT2	137
170	STH(NA)=(SXXEN+SYEN)/2.+PSD+(SXXEN-SYEN)/2.*(COS2TH(NA)*COSR-	BFRACT2	138
1	SIN2TH(NA)*SINR)+TXYEN*(SIN2TH(NA)*COSR+COS2TH(NA)*SINR)	BFRACT2	139
	SINR=SIN(2.*(R+DR))	BFRACT2	140
	COSR=COS(2.*(R+DR))	BFRACT2	141
	NC=0	BFRACT2	142
	ETAU=0.	BFRACT2	143
	IF (TAUD.GT.0.) ETAU=EXP(A1*AMIN1(0.,PSD+SDH-TSR(M,2)))*TAUD	BFRACT2	144
1220	CONTINUE	BFRACT2	145
C*****		BFRACT2	146
C	BEGIN ITERATION LOOP	BFRACT2	147
C*****		BFRACT2	148
200	CONTINUE	BFRACT2	149
	NC=NC+1	BFRACT2	150

SUBROUTINE BFRACT (Continued)

C ***	COMPUTE PRESSURE	BFRACT2	151
	PA=EQSTCM*(TEMP1/(VSO+DVS)-1.)	BFRACT2	152
	TAU=ETAU*EXP(AMIN1(2.,A1/2.*(PA-PSO)))	BFRACT2	153
	FU1=AMAX1(0.,AMIN1(1.,(1.-TAU)/(1.-TSR(M,12))))	BFRACT2	154
	VV=VH-FU1*(VSO+DVS)	BFRACT2	155
C ***	COMPUTE DEVIATOR STRESS	BFRACT2	156
	RED=AMAX1(0.,1.-4.*VV*DH)	BFRACT2	157
	RED1=AMAX1(1.-SMF*VV*DH,0.)	BFRACT2	158
	WS1=-.66667*(DOLD-DH)/(DOLD+DH)	BFRACT2	159
	BETA=2.*TXYE*DRGT/NLGGP*DV/DVO	BFRACT2	160
	ELMUF=RED1*2.*ELMU	BFRACT2	161
	TXYE=TXYE+ELMUF*EXY+(SYEEN-SXXEN)*DRGT*DELV/DVO	10/8/79	59
	SXXE=SXXEN+ELMUF*(EXX-WS1)+BETA	BFRACT2	163
	SYE=SYEEN+ELMUF*(EYY-WS1)-BETA	BFRACT2	164
	STTE=STTEN+ELMUF*(ETT-WS1)	BFRACT2	165
	WS4=SXXE**2+SYE**2+STTE**2+2.*TXYE**2	BFRACT2	166
	YE=YT*F*RED	BFRACT2	167
	IF (WS4 .LE. YE**2/1.5) GO TO 230	BFRACT2	168
	WS3=YE/SQRT(1.5*WS4)	BFRACT2	169
	SXXE=SXXE*WS3	BFRACT2	170
	SYE=SYE*WS3	BFRACT2	171
	TXYE=TXYE*WS3	BFRACT2	172
	STTE=STTE*WS3	BFRACT2	173
230	CONTINUE	BFRACT2	174
C ***	COMPUTATION OF CRACK VOLUME FROM ELASTIC OPENING, GROWTH,	BFRACT2	175
C	NUCLEATION AND FRAGMENTATION	BFRACT2	176
	VVA=0.	BFRACT2	177
	TAU=0.	BFRACT2	178
	DO 250 NA=1,NANG	BFRACT2	179
	IF (NA .LT. NANG) GO TO 237	BFRACT2	180
	STHW=STTE+PA	BFRACT2	181
	GO TO 240	BFRACT2	182
237	STHW=PA+(SXXE+SYE)/2.+(SXXE-SYE)/2.*(COS2TH(NA)*COSR-SIN2TH(NA)*	BFRACT2	183
1	SINR)+TXYE*(SIN2TH(NA)*COSR+COS2TH(NA)*SINR)	BFRACT2	184
240	SAVG=(STH(NA)+STHW)/2.	BFRACT2	185
	DTC=CN(NA)*DH/DOLD*CL(NA)	BFRACT2	186
	IF (SAVG .LT. TSR(M,2)) DTC=DTC*EXP(A1*(SAVG-TSR(M,2)))	BFRACT2	187
	SCN=SAVG-TSR(M,9)*(PSO+PA)/2.-TSR(M,5)	BFRACT2	188
	DTN=0.	BFRACT2	189
	IF (SCN .LT. 0.) DTN=TSR(M,4)*EXP(SCN/TSR(M,6))*DT*FNUC(NA)	BFRACT2	190
1	*TSR(M,3)	BFRACT2	191
	IF (STHW .LT. 0.) VVA=VVA-VCR(M)*STHW*(DTC+DTN)	BFRACT2	192
250	TAU=TAU+DTC+DTN	BFRACT2	193
	VVA=VVA/DH	BFRACT2	194
	TAU=VFR(M)*TAU	BFRACT2	195
	FU1=AMAX1(0.,AMIN1(1.,(1.-TAU)/(1.-TSR(M,12))))	BFRACT2	196
C ***	COMPUTE CHANGES IN V AND IN V SUB S	BFRACT2	197
	SDH=AMIN1(SXXE,SYE,STTE)	BFRACT2	198
	DVSA=DVS	BFRACT2	199
	DELVA=DVS+VVA-VVO	BFRACT2	200
	PJ=PA	BFRACT2	201
C		BFRACT2	206
C ***	TEST FOR COMPLETION OF ITERATIONS	BFRACT2	207
	IF (ABS(DELVA-DELV)/VSO .LT. 2.E-5) GO TO 300	BFRACT2	208
	IF (NC .GE. 30) GO TO 450	BFRACT2	209
C	DELVA IS RECENT VALUE, DELVB IS LARGER STORED VALUE, AND	BFRACT2	210
C	DELVC IS SMALLER STORED VALUE.	BFRACT2	211
	IF (NC .EQ. 1) GO TO 270	BFRACT2	212
	IF (NC .EQ. 2) GO TO 260	BFRACT2	213
	IF (DELVC .GT. DELV) GO TO 265	BFRACT2	214
	IF (DELVB .LT. DELV) GO TO 260	BFRACT2	215
	IF (DELVA .GT. DELV) GO TO 265	BFRACT2	216
C	INTERPOLATION TO FIND DVS	BFRACT2	217
260	DVS=DVSA+(DVSB-DVSA)/(DELVB-DELVA)*(DELV-DELVA)	BFRACT2	218
	IF (MOD(NC+2,3) .EQ. 0) DVS=0.5*(DVSA+DVSB)	BFRACT2	219
	GO TO 280	BFRACT2	220
265	DVS=DVSA+(DVSC-DVSA)/(DELVC-DELVA)*(DELV-DELVA)	BFRACT2	221
	IF (MOD(NC+2,3) .EQ. 0) DVS=0.5*(DVSA+DVSC)	BFRACT2	222
	GO TO 280	BFRACT2	223
270	PJ=PA+(DELV-DELVA)/(VVA*(1./(PA+SDH/2.))+A1/2.)-TEMP1/(EQSTCM+PA)	BFRACT2	224
	IF (PJ .LT. 0. .OR. PA .GE. 0.) GO TO 279	BFRACT2	225

SUBROUTINE BFRACT (Continued)

PJ=PA+EQSTCM*(VVA-DELV)/VS0	BFRACT2	226
IF (PJ .LT. 0.) PJ=AMAX1(PJ,PA)/2.	BFRACT2	227
279 PJ=PA+SIGN(AMIN1(ABS(PJ-PA),DPJ),DELVA-DELV)	BFRACT2	228
DVS=TEMP1/(1.+PJ/EQSTCM)-VS0	BFRACT2	229
280 IF (NC .GT. 2) GO TO 285	BFRACT2	230
IF(NC.EQ.1)GO TO 290	BFRACT2	231
IF (DELVA .LT. DELVB) 293,289	BFRACT2	232
285 IF (DELVA .GT. DELVB .OR. DELVA .LT. DELVC) GO TO 287	BFRACT2	233
IF (DELVA .LT. DELV) 293,290	BFRACT2	234
287 IF (DELVB .LT. DELV .AND. DELVA .GT. DELVB) GO TO 289	BFRACT2	235
IF (DELVC .GT. DELV .AND. DELVA .GT. DELVC) 292,200	BFRACT2	236
289 DELVC=DELVB	BFRACT2	237
DVSC=DVSB	BFRACT2	238
290 DELVB=DELVA	BFRACT2	239
DVSB=DVSA	BFRACT2	240
GO TO 200	BFRACT2	241
292 DELVB=DELVC	BFRACT2	242
DVSB=DVSC	BFRACT2	243
293 DELVC=DELVA	BFRACT2	244
DVSC=DVSA	BFRACT2	245
GO TO 200	BFRACT2	246
C	BFRACT2	247
C	BFRACT2	248
ENDING ROUTINE	BFRACT2	248
300 CONTINUE	BFRACT2	249
NT=0.	BFRACT2	250
R=R+DR	BFRACT2	251
DO 320 NA=1,NANG	BFRACT2	252
IF (NA .LT. NANG) GO TO 307	BFRACT2	253
STHW=STTE+PJ \$ GO TO 310	BFRACT2	254
307 STHW=PJ+(SXXE+SYYE)/2.+(SXXE-SYYE)/2.*(COS2TH(NA)*COSR-SIN2TH(NA)*	BFRACT2	255
1 SINR)+TXYE*(SIN2TH(NA)*COSR+COS2TH(NA)*SINR)	BFRACT2	256
310 SAVG=(STH(NA)+STHW)/2.	BFRACT2	257
STH(NA)=STHW	BFRACT2	258
SCN=SAVG-TSR(M,9)*(PS0+PJ)/2.-TSR(M,5)	BFRACT2	259
DN=0.	BFRACT2	260
IF (SCN .LT. 0.) DN=TSR(M,4)*EXP(SCN/TSR(M,6))*DT*FNUC(NA)	BFRACT2	261
CN0=CN(NA)	BFRACT2	262
CN(NA)=CN(NA)*DH/D0LD+DN	BFRACT2	263
IF (CN(NA) .EQ. 0.) GO TO 320	BFRACT2	264
CL(NA)=(CN0*CL(NA)*EXP(A1*AMIN1(SAVG-TSR(M,2),0.))+	BFRACT2	265
1 DN*TSR(M,3))/CN(NA)	BFRACT2	266
NT=NT+CN(NA)	BFRACT2	267
320 CONTINUE	BFRACT2	268
350 NM=(VVA+(1.-FU1)*(VS0+DVS))*DH	BFRACT2	269
FU2D=FU1	BFRACT2	270
PS0=PJ	BFRACT2	271
IF (FU1 .LT. 0.01) GO TO 400	BFRACT2	272
PJ=PJ*FU1*(VS0+DVS)*DH	BFRACT2	273
SXXEN=SXXE	BFRACT2	274
SYyen=SYYE	BFRACT2	275
STTEN=STTE	BFRACT2	276
TXyen=TXYE	BFRACT2	277
P=PJ	BFRACT2	278
Y=YT	BFRACT2	279
C	BFRACT2	280
*****	BFRACT2	281
C	BFRACT2	282
END OF SUBCYCLING LOOP	BFRACT2	282
C	BFRACT2	283
*****	BFRACT2	283
VV0=VVA	BFRACT2	284
VS0=VS0+DVS	BFRACT2	284
FU0=FU1	BFRACT2	285
380 D0LD=DH	BFRACT2	286
R0T=R	BFRACT2	287
IF(LS .EQ. 2)GO TO 500	BFRACT2	288
RETURN	BFRACT2	289
C	BFRACT2	290
C	BFRACT2	291
END WITH SEPARATION	BFRACT2	291
400 CONTINUE	BFRACT2	292
SXXEN=0.	BFRACT2	293
SYyen=0.	BFRACT2	294
STTEN=0.	BFRACT2	295
TXyen=0.	BFRACT2	296
P=0.	BFRACT2	297
Y=YT	BFRACT2	298
NM=-ABS(NM)	BFRACT2	299
RETURN	BFRACT2	300

SUBROUTINE BFRACT (Continued)

410	CONTINUE SXXEN=0. SYTEN=0. STTEN=0. TXTEN=0. EMU=1./V0-1. P=(EQSTCM*EMU)*(1.-.5*EQSTGM*EMU)+EQSTGM*E*RHOS/V0 IF(P.LT.0.) P=0. IF(LS.EQ.2)GO TO 500 RETURN	BFRACT2 301 BFRACT2 302 BFRACT2 303 BFRACT2 304 BFRACT2 305 BFRACT2 306 BFRACT2 307 BFRACT2 308 BFRACT2 309 BFRACT2 310 BFRACT2 311
C	*** PROVISION FOR ABORT IN CASE OF ITERATION FAILURE	BFRACT2 312
450	NTRY=NTRY+1 IF (NTRY .GE. 5) GO TO 460 DV=V0/RHOS-1./D0LD NL0LD=NLOOP NL00P=MAX1(3.,-4.*2.**NTRY*DV*EQSTCM/V0/TSR(M,5)+0.5,2.*NL00P) IF (TSR(M,6).GT.0.)NL00P=MIN1(AMAX1(3.,4.*2.**NTRY*DV*EQSTCM/V0 1 /3.E9+0.5,2.*NL0LD),10.*NL0LD) GO TO 100	BFRACT2 313 BFRACT2 314 BFRACT2 315 BFRACT2 316 BFRACT2 317 BFRACT2 318 BFRACT2 319
460	PRINT 1600,NN,KS,JS,SDH,P,DV,DELVA,DELBV,DELV,DV0,V0 IF (NTRY .EQ. 5) STOP 22 NT=0. R=R+DR TAU=0. DO 620 NA=1,NANG IF (NA .LT. NANG) GO TO 607 STHW=STTE+PJ \$ GO TO 610	BFRACT2 320 BFRACT2 321 BFRACT2 322 BFRACT2 323 BFRACT2 324 BFRACT2 325 BFRACT2 326 BFRACT2 327 BFRACT2 328
607	STHW=PJ+(SXXE+SYTE)/2.+(SXXE-SYTE)/2.*(COS2TH(NA)*COSR-SIN2TH(NA)* 1 SINR)+TXTE*(SIN2TH(NA)*COSR+COS2TH(NA)*SINR)	BFRACT2 329 BFRACT2 330
610	SAVG=(STH(NA)+STHW)/2. SCN=SAVG-TSR(M,9)*(P0+PJ)/2.-TSR(M,5) DN=0. IF (SCN .LT. 0.) DN=TSR(M,4)*EXP(SCN/TSR(M,6))*DT*FNUC(NA) CN0=CN(NA) CN(NA)=CN(NA)*DH/D0LD+DN IF(CN(NA) .EQ. 0.) GO TO 620 CL(NA)=(CN0*CL(NA)*EXP(A1*AMIN1(SAVG-TSR(M,2),0.))+ 1 DN*TSR(M,3))/CN(NA) NT=NT+CN(NA)	BFRACT2 331 BFRACT2 332 BFRACT2 333 BFRACT2 334 BFRACT2 335 BFRACT2 336 BFRACT2 337 BFRACT2 338 BFRACT2 339
620	TAU=TAU+CN(NA)*CL(NA) TAU=VFR(M)*TAU FU1=AMAX1(0.,AMIN1(1.,(1.-TAU)/(1.-TSR(M,12)))) FU2D=FU1 NM=(VVA+(1.-FU1)*(V0+DVS))*DH IF (FU1 .LT. 0.01) GO TO 400 PJ=PJ*FU1*(V0+DVS)*DH EEST=EEST+(P0-PJ)*DELV SXXEN=SXXE STTEN=STTE TXTEN=TXTE P=PJ Y=YT VVO=VVA V0=V0+DVS D0LD=DH ROT=R IF(LS .EQ. 2)GO TO 500 RETURN	BFRACT2 340 BFRACT2 341 BFRACT2 342 BFRACT2 343 BFRACT2 344 BFRACT2 345 BFRACT2 346 BFRACT2 347 BFRACT2 348 BFRACT2 349 BFRACT2 350 BFRACT2 351 BFRACT2 352 BFRACT2 353 BFRACT2 354 BFRACT2 355 BFRACT2 356 BFRACT2 357 BFRACT2 358 BFRACT2 359
C	FINAL PRINTOUT	BFRACT2 360
C		BFRACT2 361
C		BFRACT2 362
500	IZER0=1 IF (NT .EQ. 0.) GO TO 520 IZER0=2 CNSUM=0. CRIT2=0. CRIT3=0. DO 510 NA=1,NANG CL3(NA)=CL(NA)**(.3333333333) CRIT2=CRIT2+CN(NA)*CL3(NA)**2 CNSUM=CNSUM+CN(NA)	BFRACT2 363 BFRACT2 364 BFRACT2 365 BFRACT2 366 BFRACT2 367 BFRACT2 368 BFRACT2 369 BFRACT2 370 BFRACT2 371
510	CRIT3=CRIT3+CN(NA)*CL(NA) IF(CNSUM .EQ. 0.) GO TO 520 CRIT2=3.1416*CRIT2	BFRACT2 372 BFRACT2 373 BFRACT2 374 BFRACT2 375

SUBROUTINE BFRACT (Concluded)

RAD=(CRIT3/CNSUM)**(1./3.)	BFRACT2	376
FRAGRAD=0.	BFRACT2	377
FRAGNUM=0.	BFRACT2	378
IF(FU2D.EQ.1.)GO TO 515	BFRACT2	379
FRAGRAD=RAD*TSR(M,11)	BFRACT2	380
FRAGNUM=CNSUM*TSR(M,10)*(1.-FU2D)	BFRACT2	381
515 CONTINUE	BFRACT2	382
PRINT 1510,(CL3(I),I=1,5),RAD,CRIT2,ROT,FU2D,KS,JS,(CN(I),I=1,5),	BFRACT2	383
1 CNSUM,FRAGRAD,FRAGNUM	BFRACT2	384
520 CONTINUE	BFRACT2	385
RETURN	BFRACT2	386
1510 FORMAT(13H0CELL CL = 1P4E10.3,2X,E10.3,11H CL-AVG = E10.3,	BFRACT2	387
1 12H PI*N*R**2=OPF6.0,6H ROT=F6.0,5H FU=F6.4/2I3,7H CN =	BFRACT2	388
2 1P4E10.3,2X,E10.3,10H CN-TOT =E10.3,16H FRAGMENT RAD.=E10.3,	BFRACT2	389
3 6H NO.=E10.3)	BFRACT2	390
1600 FORMAT(32H ITERATION FAILURE IN BFRACT, N=I5,4H, K=I3,4H, J=I3,	BFRACT2	391
1 1P5E12.3/5X,1P3E12.3)	BFRACT2	392
END	BFRACT2	393

SUBROUTINE CAP1

	SUBROUTINE CAP1(LS,IN,M,N,IH,DH,DORG,E,EX,EY,EZ,EXY,SX,SY, 1 SZ,SNY,ZEVP,K,J,TEVP)	CAP1	2
C		CAP1	3
C	CAP1 - WRITTEN BY L. SEAMAN - INSERTED INTO THE COPS CODE 10 - 78	CAP1	4
C		CAP1	5
C	*****	CAP1	6
C	DEFINITION OF INDICATOR -IH-	CAP1	7
C	5 - ELASTIC	CAP1	8
C	6 - MOHR-COULOMB SURFACE	CAP1	9
C	7 - CAP SURFACE	CAP1	10
C	8 - CAP AND MOHR-COULOMB	CAP1	11
C	9 - CONSOLIDATED	CAP1	12
C	10 - SEPARATION	CAP1	13
	INTEGER DBUG1,DBUG2	CAP1	14
	REAL MUP,MUP2	CAP1	15
	DIMENSION INIT(4),AMC1(4),AMC2(4),AMC3(4),AMC4(4),AMC5(4), 1 AMC6(4),AK(4),AK2(4),MUP(4),MUP2(4),NREG(4),DAMG(4),	CAP1	16
	2 SCRIT(4),W2(4),AKSOL(4)	CAP1	17
	DIMENSION PA(5),AJ(5),DL(2)	CAP1	18
	COMMON /EQS/ EQSTC(6),EQSTD(6),EQSTE(6),EQSTG(6),EQSTH(6),EQSTN(6)	CAP1	19
	1 ,EQSTS(6),RH0(6),RH0S(6),YC(6),YAD(6),MU(6),ESC(6,20),CLIN,CQSQ,	CAP1	20
	2 TRIQ,AMAT(6,4),SP(6),G2(6),PMIN(6)	CAP1	21
	COMMON /POR/ PORa(6,5),PORB(6,5),PORC(6,5),EVP(6,5)	CAP1	22
	DATA INIT/4*0/	CAP1	23
	GH(X)=MUP(M)+MUP2(M)*AMIN1(AMC1(M),X)	CAP1	24
	GG(X,Y)=MUP(M)+MUP2(M)*AMIN1(AMC1(M),0.5*(X+Y))	CAP1	25
	BKK(X,Y)=AMIN1(AKSOL(M),AK(M)+AK2(M)*AMIN1(0.,.5*(X+Y)))	CAP1	26
	BKH(X)=AMIN1(AKSOL(M),AK(M)+AK2(M)*AMIN1(0.,X))	CAP1	27
C		CAP1	28
	IF (LS) 30,30,50	CAP1	29
C	*****	CAP1	30
C	READ AND INITIALIZE MATERIAL ARRAYS.	CAP1	31
C	*****	CAP1	32
	30 IF(INIT(M).EQ. M) GO TO 50	CAP1	33
	INIT(M)=M	CAP1	34
	READ (IN,1020)A1,A2,AK(M),A3,A4,AK2(M),A5,A6,MUP(M),A7,A8,MUP2(M)	CAP1	35
	PRINT 1040, A1,A2,AK(M),A3,A4,AK2(M),A5,A6,MUP(M),A7,A8,MUP2(M)	CAP1	36
	PRINT 1021,IN	CAP1	37
	READ (IN,1022)A1,A2,AMC1(M),AMC2(M),AMC3(M),AJ10,EN	CAP1	38
	PRINT 1042, A1,A2,AMC1(M),AMC2(M),AMC3(M),AJ10,EN	CAP1	39
	AMC4(M)=-(AMC1(M)+AMC2(M)*EXP(AJ10/AMC3(M)))*EXP(-EN)	CAP1	40
	AMC5(M)=AJ10/EN	CAP1	41
	AMC6(M)=AJ10	CAP1	42
	PRINT 1021,IN	CAP1	43
	READ (IN,1020)A1,A2,SCRIT(M),A3,A4,DAMG(M),A5,A6,AKSOL(M)	CAP1	44
	IF (AKSOL(M).LT. AK(M)) AKSOL(M)=2.*AK(M)	CAP1	45
	PRINT 1040, A1,A2,SCRIT(M),A3,A4,DAMG(M),A5,A6,AKSOL(M)	CAP1	46
	PRINT 1021,IN	CAP1	47
	READ (IN,1022)A1,A2,(EVP(M,1),I=1,5)	CAP1	48
	PRINT 1042, A1,A2,(EVP(M,1),I=1,5)	CAP1	49
	PRINT 1021,IN	CAP1	50
	READ (IN,1024)A1,A2,NREG(M),A3,A4,NPRCAP,A5,A6,P1,A7,A8,W2(M)	CAP1	51
	PRINT 1044, A1,A2,NREG(M),A3,A4,NPRCAP,A5,A6,P1,A7,A8,W2(M)	CAP1	52
	PRINT 1021,IN	CAP1	53
C	COMPUTATION OF PARAMETERS ON HYDROSTAT	CAP1	54
	PORa(M,1)=P1	CAP1	55
	PORB(M,1)=0.	CAP1	56
	PORC(M,1)=0.	CAP1	57
	NP=MINO(NREG(M),4)	CAP1	58
	DO 15 NQ=1,NP	CAP1	59
	READ (IN,1020)A1,A2,P2,A3,A4,DELP	CAP1	60
	PRINT 1040, A1,A2,P2,A3,A4,DELP	CAP1	61
	PRINT 1021,IN	CAP1	62
	DE=EVP(M,NQ+1)-EVP(M,NQ)	CAP1	63
	DP=4.*DELP/DE	CAP1	64
	PORa(M,NQ+1)=P1-EVP(M,NQ)/DE*(P2-P1+DP*EVP(M,NQ+1))	CAP1	65
	PORB(M,NQ+1)=(P2-P1+DP*(EVP(M,NQ)+EVP(M,NQ+1)))/DE	CAP1	66
	PORC(M,NQ+1)=-DP/DE	CAP1	67
15	P1=P2	CAP1	68
	EVP(M,5)=EVP(M,NP+1)	CAP1	69
C	SET ACCURACY CRITERIA	CAP1	70
	NMAX=30	CAP1	71
	FCR1=60.	CAP1	72
	FCR2=300.	CAP1	73
	DFCR1=1.E5	CAP1	74
C	SET LPATH=0 FOR CONSTANT VOLUME ON M-C, =1 FOR NORMALITY	CAP1	75
	LPATH=1	CAP1	76

SUBROUTINE CAP1 (Continued)

	PRINT 1004,FCR1,FCR2,DFCR1,NMAX,LPATH	CAP1	77
1004	FORMAT (* ACCURACY AND SUBCYCLING CRITERIA FCR1,FCR2 =*1P2E10.3,	CAP1	78
1	* DFCR1,NMAX=* E10.3,14,/* MOHR-COULOMB PATH, LPATH=*12,	CAP1	79
2	* - 0 - FOR CONSTANT VOLUME, - 1 - FOR NORMALITY*)	CAP1	80
C		CAP1	81
	DEBUG1=0	CAP1	82
	DEBUG2=1	CAP1	83
	IF(DEBUG2.EQ.0) GO TO 41	CAP1	84
	DO 31 I=1,5	CAP1	85
	PA(I)=(I+1)*PORA(M,1)/2.	CAP1	86
31	AJ(I)=0.	CAP1	87
	PRINT 3000,(PA(I),I=1,5)	CAP1	88
3000	FORMAT (*1MOHR-COULOMB AND CAP COORDINATES*/20X,*J1*,9X,*M-C*,	CAP1	89
1	9X,*J2 ON CAPS CORRESPONDING TO PR VALUES*/32X,*J2*,1P5E12.3)	CAP1	90
	I1=0	CAP1	91
	AJ2=0.	CAP1	92
	PRINT 3001,I1,AJ10,AJ2	CAP1	93
3001	FORMAT (I10,1P7E12.3)	CAP1	94
	DP=0.2*PORA(M,1)	CAP1	95
	DO 32 I=1,5	CAP1	96
32	PA(I)=PA(I)**2	CAP1	97
	DO 40 I1=1,50	CAP1	98
	AJ1=AJ10+I1*DP	CAP1	99
	AJ2=AMC1(M)+AMC2(M)*EXP(AJ1/AMC3(M))+AMC4(M)*EXP(AJ1/AMC5(M))	CAP1	100
	IF (AJ1.GT. 0.) GO TO 38	CAP1	101
	PP=AJ1**2/9.	CAP1	102
	DO 35 JJ=1,5	CAP1	103
	AJ(JJ)=0.	CAP1	104
	IF (PP.GE. PA(JJ)) GO TO 35	CAP1	105
	AJ(JJ)=SQRT(W2(M)*(PA(JJ)-PP))	CAP1	106
35	CONTINUE	CAP1	107
38	CONTINUE	CAP1	108
	PRINT 3001,I1,AJ1,AJ2,(AJ(I),I=1,5)	CAP1	109
40	CONTINUE	CAP1	110
41	CONTINUE	CAP1	111
	RETURN	CAP1	112
C		CAP1	113
C	*****	CAP1	114
C	COMPUTATION OF STRESS	CAP1	115
C	*****	CAP1	116
50	AJ10=SX+SY+SZ	CAP1	117
	PO=AJ10/3.	CAP1	118
	NRE=0	CAP1	119
	DOLD=DORG	CAP1	120
	EPRAT1=EPRAT2=0.25	CAP1	121
	RR=1.	CAP1	122
	RSUM=0.	CAP1	123
	IF (DEBUG1.EQ.1) PRINT 1052,N,K,J,IH,SX,SY,SZ,SXY,EX,EY,EXY,TEVP,	CAP1	124
1	ZEVP,DH,DORG	CAP1	125
1052	FORMAT (*OBEGIN CAP N,K,J,IH=*4I4,* SX,SY,SZ,SXY=*1P4E10.3,	CAP1	126
1	* EX,EY,EXY=*3E10.3/ 10X,* TEVP,ZEVP=*2E10.3,* DH,DORG=*0P2F10.6	CAP1	127
2	)	CAP1	128
	ZEVT=ALOG(DORG/DH)	CAP1	129
	EZ=ZEVT-EX-EY	CAP1	130
	DEVT=ZEVT	CAP1	131
C	RECOMBINATION OF SPALLED MATERIAL.	CAP1	132
	IF (IH.NE. 10) GO TO 80	CAP1	133
	TEVP=TEVP+ZEVT	CAP1	134
	IF(TEVP.GT.0.) GO TO 580	CAP1	135
	DE3=(ZEVT-TEVP)/3.	CAP1	136
	EX=EX-DE3	CAP1	137
	EY=EY-DE3	CAP1	138
	EZ=EZ-DE3	CAP1	139
	ZEVT=TEVP	CAP1	140
	TEVP=-1.	CAP1	141
	IH=5	CAP1	142
80	CONTINUE	CAP1	143
	AJ20=SQRT(((SX-PO)**2+(SY-PO)**2+(SZ-PO)**2)/2.+SXY**2)	CAP1	144
	EV=DEVT/3.	CAP1	145
C	*****	CAP1	146
C	COMPUTE STRESSES ON ELASTIC BASIS AND TEST FOR YIELDING.	CAP1	147
	BG=GH(AJ20)	CAP1	148
	SXT=(SX-PO)+2.*BG*(EX-EV)	CAP1	149
	SYT=(SY-PO)+2.*BG*(EY-EV)	CAP1	150
	SZT=(SZ-PO)+2.*BG*(EZ-EV)	CAP1	151

SUBROUTINE CAP1 (Continued)

	SXYT=SXY+2.*BG*EXY	CAP1	152
	AJ2T=SQRT((SXT**2+SYT**2+SZT**2)/2.+SXYT**2)	CAP1	153
	ZEIT=(AJ2T-AJ20)/(2.*BG)	CAP1	154
	IF (MUP2(M).EQ. 0.) GO TO 95	CAP1	155
95	AJ2T=(MUP(M)/MUP2(M)+AJ20)*EXP(2.*MUP2(M)*ZEIT)-MUP(M)/MUP2(M)	CAP1	156
	BG=GG(AJ2T,AJ20)	CAP1	157
	AJ2T=AMIN1(AJ2T,AJ20+2.*BG*ZEIT)	CAP1	158
	BK=(AK(M)+AK2(M)*AJ10)*(1.+1.5*AK2(M)*ZEVT*(1.+AK2(M)*ZEVT))	CAP1	159
	BK= AMIN1(AKSOL(M),AMAX1(BK,AK(M)))	CAP1	160
	AJ1T=AJ10+3.*BK*ZEVT	CAP1	161
	D=DH	CAP1	162
	PAT=AJ1T/3.	CAP1	163
	PT=PAT	CAP1	164
	F10=AJ20-(AMC1(M)+AMC2(M)*EXP(AJ10/AMC3(M))+AMC4(M)*EXP(AJ10/	CAP1	165
	1 AMC5(M)))	CAP1	166
	AMC=AMC1(M)	CAP1	167
	IF(AJ1T.LT.-5.*(AMC3(M)+AMC5(M)))GO TO 110	CAP1	168
	AMC=-AJ1T	CAP1	169
	IF(AJ1T.GT.AMC6(M))GO TO 110	CAP1	170
	AMC= AMC1(M)+AMC2(M)*EXP(AJ1T/AMC3(M))+AMC4(M)*EXP(AJ1T/	CAP1	171
	1 AMC5(M))	CAP1	172
110	F1T=AJ2T-AMC	CAP1	173
C		CAP1	174
C	COMPUTATION OF F2T.	CAP1	175
	CALL CAPPR(PT,ZEVT,M,DOLD,IHH,YM)	CAP1	176
	F2T=AJ2T**2/W2(M)+AJ1T**2/9.-PT**2	CAP1	177
	F20=AJ20**2/W2(M)+AJ10**2/9.-PT**2	CAP1	178
	IF (DEBUG1.EQ. 1)	CAP1	179
	1PRINT 1145,AJ1T,AJ2T,AJ10,AJ20,BK,BG,ZEVT,ZEIT,F1T,F2T,F10,F20,PT	CAP1	180
1145	FORMAT (* -145- J1T,J2T,J10,J20=*1P4E10.3,* BK,BG,ZEVT,ZEIT=*1	CAP1	181
	1 4E10.3,/ 10X,*F1T,F2T,F10,F20=*4E10.3,* PT=*E10.3)	CAP1	182
C		CAP1	183
C	TEST FOR PURELY ELASTIC CASE.	CAP1	184
	IF (F1T.LE. 0. .AND. F2T.LE. 0.) GO TO 500	CAP1	185
C	*****	CAP1	186
C	BEGIN SUBCYCLING LOOP OVER EACH STRAIN INCREMENT.	CAP1	187
C	*****	CAP1	188
	NINC=MAX1(1.,FCR1*ABS(AJ1T-AJ10)/BK,FCR2*(AJ2T-AJ20)/BG)	CAP1	189
	IF(NINC.GT.40.OR.DEBUG1.EQ.1) PRINT 1195,K,J,N,NINC,AJ1T,AJ2T,AJ10,	CAP1	190
	1 AJ20	CAP1	191
1195	FORMAT (30H CAP SUBCYCLING - K,J,N,NINC =314,110,* J1T,J2T,J10,J2	CAP1	192
	10=*1P4E10.3)	CAP1	193
	RR=1./AMINO(600,NINC)	CAP1	194
	NINC=0	CAP1	195
C		CAP1	196
C	SET INITIAL STRAIN INCREMENT.	CAP1	197
200	NINC=NINC+1	CAP1	198
	D=DOLD*EXP(-ZEVT*RR)	CAP1	199
	DEVT=ZEVT*RR	CAP1	200
	AJ10=SX+SY+SZ	CAP1	201
	PO=AJ10/3.	CAP1	202
	AJ20=SQRT(((SX-PO)**2+(SY-PO)**2+(SZ-PO)**2)/2.+SXY**2)	CAP1	203
C	COMPUTE STRESS INVARIANTS.	CAP1	204
	BK=(AK(M)+AK2(M)*AJ10)*(1.+1.5*AK2(M)*DEVT*(1.+AK2(M)*DEVT))	CAP1	205
	BK= AMIN1(AKSOL(M),AMAX1(BK,AK(M)))	CAP1	206
	AJ1T=AJ10+3.*BK*DEVT	CAP1	207
	PAT=AJ1T/3.	CAP1	208
	EV=DEVT/3.	CAP1	209
	BG=GH(AJ20)	CAP1	210
	SXT=(SX-PO)+2.*BG*(EX*RR-EV)	CAP1	211
	SYT=(SY-PO)+2.*BG*(EY*RR-EV)	CAP1	212
	SZT=(SZ-PO)+2.*BG*(EZ*RR-EV)	CAP1	213
	SXYT=SXY+2.*BG*EXY*RR	CAP1	214
	AJ2T=SQRT((SXT**2+SYT**2+SZT**2)/2.+SXYT**2)	CAP1	215
	IF (MUP2(M).EQ. 0) GO TO 205	CAP1	216
	DEIT=(AJ2T-AJ20)/(2.*BG)	CAP1	217
	AJ2T=(MUP(M)/MUP2(M)+AJ20)*EXP(2.*MUP2(M)*DEIT)	CAP1	218
	1 -MUP(M)/MUP2(M)	CAP1	219
205	BG=GG(AJ2T,AJ20)	CAP1	220
	AJ2T=AMIN1(AJ2T,AJ20+2.*BG*DEIT)	CAP1	221
	IF (DEBUG1.EQ.1) PRINT 1205,AJ10,AJ1T,AJ20,AJ2T,BK,BG,DEVT,DEIT,	CAP1	222
	1 RR,RSUM,D,DOLD	CAP1	223
1205	FORMAT (* LOC=205 J10,J1T,J20,J2T=*1P4E10.3,* BK,BG=*2E10.3,	CAP1	224
	1 /10X,* DEVT,DEIT=*2E10.3,* RR,RSUM=*2E10.3,* D,DOLD=*0P2F10.6)	CAP1	225
C		CAP1	226

SUBROUTINE CAP1 (Continued)

C	EVALUATE F1 AND F2 FROM ELASTIC STRESSES.	CAP1	227
	AMC=AMC1(M)	CAP1	228
	IF(AJ1T.LT.-5.*(AMC3(M)+AMC5(M)))GO TO 215	CAP1	229
	AMC=-AJ1T	CAP1	230
	IF(AJ1T.GT.AMC6(M))GO TO 215	CAP1	231
	AMC=AMC1(M)+AMC2(M)*EXP(AJ1T/AMC3(M))+AMC4(M)*EXP(AJ1T/	CAP1	232
	1 AMC5(M))	CAP1	233
215	F1T=AJ2T-AMC	CAP1	234
	CALL CAPPR(PT,ZEVP,M,DOLD,IHH,YM)	CAP1	235
C	COMPUTE F2 FROM ELASTIC STRESSES AND PREVIOUS PLASTIC STRAIN.	CAP1	236
245	F2T=AJ2T**2/W2(M)+AJ1T**2/9.-PT**2	CAP1	237
	DZEP=AMIN1(-1.E-5,DEVT)	CAP1	238
	ZEP=ZEVP+DZEP	CAP1	239
	CALL CAPPR(PZ,ZEP,M,D,IHH,YM)	CAP1	240
	DPDE=3.*(PZ**2-PT**2)/DZEP	CAP1	241
	NQ=0	CAP1	242
	IF (DEBUG1 .EQ. 1)	CAP1	243
	1PRINT 1270,F1T,F2T,PT,PZ,ZEP,DZEP,RR,EPRAT1,EPRAT2	CAP1	244
1270	FORMAT (* 270 - F1T,F2T,PT,PZ=*1P4E10.3,* ZEP,DZEP=*2E10.3,	CAP1	245
	1 /10X,* RR,EPRAT1,EPRAT2=*0P3F10.6)	CAP1	246
	IF (F1T .LE. 0. .AND. F2T .LE. 0.) GO TO 500	CAP1	247
	AJ11=AJ10+EPRAT1*(AJ1T-AJ10)	CAP1	248
	AJ21=AJ20+EPRAT2*(AJ2T-AJ20)	CAP1	249
C	*****	CAP1	250
C	COMPUTATION OF YIELDING PROCESS	CAP1	251
	NQ=1	CAP1	252
	BK=BKH(AJ11)	CAP1	253
	BG=GH(AJ21)	CAP1	254
C		CAP1	255
C	YIELD ON MOHR-COULOMB SURFACE.	CAP1	256
	IF(F1T.LT.0.) GO TO 350	CAP1	258
	IF(ZEVT.GT.0.) GO TO 550	CAP1	259
	IF (F2T .GT. 0.) GO TO 400	CAP1	260
310	AJ1=AMIN1(AJ1T,AMC6(M))	CAP1	261
	NC=0	CAP1	262
	AJ2B=AJ20	CAP1	263
320	NC=NC+1	CAP1	264
	TAU2=AMC2(M)*EXP(AJ1/AMC3(M))	CAP1	265
	TAU3=AMC4(M)*EXP(AJ1/AMC5(M))	CAP1	266
	AJ2=AMC1(M)+TAU2+TAU3	CAP1	267
	IF (LPATH .EQ. 0) GO TO 330	CAP1	268
	DJ2=AJ2-AJ2B	CAP1	269
	IF (NC .GE. 10) GO TO 700	CAP1	270
	IF (ABS(DJ2) .LT. DFCR1 .AND. NC .GT. 1) GO TO 330	CAP1	271
	X11=TAU2/AMC3(M)+TAU3/AMC5(M)	CAP1	272
	BK=BKK(AJ1,AJ10)	CAP1	273
	BG=GG(AJ2,AJ20)	CAP1	274
	X1B=AMC2(M)*EXP((AJ1+AJ10)/(2.*AMC3(M)))/AMC3(M)	CAP1	275
	1 +AMC4(M)*EXP((AJ1+AJ10)/(2.*AMC5(M)))/AMC5(M)	CAP1	276
	DJ=(AJ2T-AJ2+(AJ1T-AJ1)*BG/(9.*BK*X1B))/(X11+BG/(9.*BK*X1B))	CAP1	277
	IF (DEBUG1 .EQ. 1) PRINT 1320,NC,AJ1,AJ2,DJ2,DJ,TAU2,TAU3,X11,BK,BG	CAP1	278
1320	FORMAT (* M-C NC=*I2,* J1,J2,DJ2,DJ=*1P4E12.5,* TAU,X1,K,G=*	CAP1	279
	1 5E10.3)	CAP1	280
	AJ2B=AJ2	CAP1	281
	AJ1=AJ1+DJ	CAP1	282
	GO TO 320	CAP1	283
330	F21=AJ2**2/W2(M)+AJ1**2/9.-PT**2	CAP1	284
	IF (DEBUG1 .EQ. 1) PRINT 1330,AJ1,AJ2,AJ2A,F21,F1T	CAP1	285
1330	FORMAT (* M-C END, J1,J2,J2A=*1P3E12.5,* F21,F1T=*2E10.3)	CAP1	286
	IF (F21 .GT. 0.) GO TO 410	CAP1	287
	IH=6	CAP1	288
	GO TO 600	CAP1	289
C		CAP1	290
C	YIELD ON THE CAP SURFACE	CAP1	291
C		CAP1	292
350	BB=0.	CAP1	293
	AJ10P=AJ10	CAP1	294
	AJ20P=AJ20	CAP1	295
	IF (IH .EQ. 7 .OR. IH .EQ. 8) GO TO 353	CAP1	296
	AJ10P=SIGN(PT*AJ1T/SQRT(AJ1T**2/9.+AJ2T**2/W2(M)),AJ1T)	CAP1	297
	AJ20P=SQRT(W2(M)*AMAX1(0.,PT**2-AJ10P**2/9.))	CAP1	298
	ZEP=ZEVP+AMIN1(0.,DEVT-(AJ10P-AJ10)/BK)	CAP1	299
	CALL CAPPR(PZ,ZEP,M,D,IHH,YM)	CAP1	300
353	IF (ABS(AJ1T-AJ10P) .GE. 1.) BB=(PZ-PT)/(AJ1T-AJ10P)	CAP1	301

SUBROUTINE CAP1 (Continued)

	IH=7	CAP1	302
	IL0=1	CAP1	303
	IHI=2	CAP1	304
C	FIRST ESTIMATE OF J1	CAP1	305
	NCAP=1	CAP1	306
	INT=IL0	CAP1	307
	AJ1=AJ10P*(1.+BB/(PT+BB*AJ10P))*(3.*DEVT*BKK(AJ10P))	CAP1	308
C	COMPUTATION OF J2 AND ERROR DLA	CAP1	309
355	BK=BKK(AJ1,AJ10)	CAP1	310
	DZEP=AMIN1(0.,DEVT-(AJ1-AJ10)/(3.*BK))	CAP1	311
	CALL CAPPR(PR,ZEVP+DZEP,M,D,IH,YM)	CAP1	312
	AJ1=AMAX1(AJ1,3.3*PR)	CAP1	313
	PJ=AMIN1(ABS(AJ1),ABS(AJ1-6.*PR))/3.	CAP1	314
	AJ2=0.	CAP1	315
	IF (PR**2-PJ**2.GT. 1.)	CAP1	316
	1AJ2=SIGN(SQRT(W2(M)*(PR**2-PJ**2)),AJ1-3.*PR)	CAP1	317
	BG=GG(ABS(AJ2),AJ20)	CAP1	318
	IF (IH.EQ. 9 .AND. NCAP.GE. 3) GO TO 480	CAP1	319
	DEIP=DEIT-(AJ2-AJ20P)/(2.*BG)	CAP1	320
	DLA=DEIP-1.5*(AJ2+AJ20P)*DZEP/(W2(M)*(AJ1+AJ10P))	CAP1	321
	AJA=AJ1	CAP1	322
	IF (DEBUG1.EQ. 1)	CAP1	323
	1PRINT 1365,NCAP,AJ1,AJ2,DLA,BG,DEIP,PJ,PR	CAP1	324
1365	FORMAT (* 365 NCAP=*13,* J1,J2=*1P2E13.6,* DLA,BG,DEIP,PJ,PR=*1 5E10.3)	CAP1	325
	IF (2.*ABS(DLA)*BG.LT. DFCR1) GO TO 390	CAP1	326
	IF (NCAP.GE. 30) GO TO 700	CAP1	327
	IF (NCAP-2) 358,360,370	CAP1	328
C	SECOND ESTIMATE OF J1	CAP1	329
358	IF (ABS(AJ1).LE. 1.E4) AJ1=-3.*SQRT(AMAX1(0.,PT**2-AJ2T**2/W2(M)))	CAP1	330
	1DJ2=2.*DLA*BG	CAP1	331
	IF (ABS(AJ1).GT. 1.E4) AJ1=-9./W2(M)*ABS(AJ2)/AJ1*DJ2 + AJ1	CAP1	332
	GO TO 382	CAP1	333
360	INT=IL0	CAP1	334
	IF (DL(IL0)*DLA.LT. 0.) GO TO 375	CAP1	335
	INT=IHI	CAP1	336
	IF (AMAX1(DL(IL0),DLA).LT. 0.) GO TO 366	CAP1	337
C	MOST TENSILE ESTIMATE OF J1	CAP1	338
	AJ1=-3.*SQRT(AMAX1(0.,PT**2-AJ2T**2/W2(M)))	CAP1	339
	AJ1=0.5*(AJ1+AMAX1(AJ1T,AJ10))	CAP1	340
	GO TO 382	CAP1	341
C	MOST COMPRESSIVE ESTIMATE OF J1	CAP1	342
366	AJ1=3.*PT	CAP1	343
	IF (ABS(DEVT).LT. 1.E-7) GO TO 370	CAP1	344
	DEVZP=DEVT-(PZ-AJ10/3.)/BKK(AJ10,3.*PZ)	CAP1	345
	DEVTP=DEVT-(PT-AJ10/3.)/BKK(AJ10,3.*PT)	CAP1	346
	DEVP=DEVTP*DEVT/(DEVT+DEVTP-DEVZP)	CAP1	347
	AJ1=3.*(PT+(PZ-PT)*DEVP/DEVT)	CAP1	348
	IF (DEBUG1.EQ. 1)	CAP1	349
	1PRINT 1357,NCAP,AJ10P,AJ20P,AJ10,AJ2,DEVZP,DEVTP,DEVP,AJ1	CAP1	350
1357	FORMAT (* 357 NCAP=*13,* AJ10P,AJ20P,AJ10,AJ2=*1P4E10.3/1 * DEVZP,DEVTP,DEVP,AJ1=*4E10.3)	CAP1	351
	GO TO 382	CAP1	352
370	INT=IHI	CAP1	353
C	REGULA FALSI CALCULATION OF J1	CAP1	354
	IF (DL(IL0).GT. 0..OR. (DL(IHI).GT. 0..AND. DLA.GT. 0.))	CAP1	355
1	INT=IL0	CAP1	356
375	AJ1=AJA-(AJ(INT)-AJA)/(DL(INT)-DLA)*DLA	CAP1	357
	IF (MOD(NCAP,5).EQ. 0) AJ1=(AJ1+AJA+AJ(INT))/3.	CAP1	358
C	STORAGE OF RESULTS OF PREVIOUS ITERATIONS	CAP1	359
	INT=IHI	CAP1	360
	IF (NCAP.EQ. 2) GO TO 382	CAP1	361
	IF ((DL(IHI).GT. 0..AND. DLA.GT. DL(IHI)).OR. (DLA.LT. 1 DL(IL0).AND. DL(IL0).LT. 0.)) GO TO 385	CAP1	362
1	IF (DL(IL0).GT. 0..OR. (DL(IHI).GT. 0..AND. DLA.GT. 0.))	CAP1	363
1	GO TO 382	CAP1	364
	INT=IL0	CAP1	365
382	DL(INT)=DLA	CAP1	366
	AJ(INT)=AJA	CAP1	367
	IF (NCAP.EQ. 1) GO TO 385	CAP1	368
	IF (DL(IHI).GT. DL(IL0)) GO TO 385	CAP1	369
	INT=IHI	CAP1	370
	IHI=IL0	CAP1	371
	IL0=INT	CAP1	372
		CAP1	373
		CAP1	374
		CAP1	375
		CAP1	376

SUBROUTINE CAP1 (Continued)

385	CONTINUE	CAP1	377
	NCAP=NCAP+1	CAP1	378
	IF (DEBUG1 .EQ. 1)	CAP1	379
	1PRINT 1385,NCAP,IH1,IL0,AJ(1),AJ(2),DL(1),DL(2)	CAP1	380
1385	FORMAT (* 385 NCAP=*13,* HI,LO=*212,* AJ,DL=*1P4E10.3)	CAP1	381
	GO TO 355	CAP1	382
C	CHECK FOR CONVERGENCE TO POINT ABOVE THE M-C CURVE	CAP1	383
390	F11=AJ2-(AMC1(M)+AMC2(M)*EXP(AJ1/AMC3(M))+AMC4(M)*EXP(AJ1/	CAP1	384
	1 AMC5(M)))	CAP1	385
	DJ2=2.*DLA*BG	CAP1	386
	IF (ABS(AJ1) .GE. 1.E4) AJ1=-9./W2(M)*ABS(AJ2)/AJ1*DJ2 +AJ1	CAP1	387
	AJ2=AMAX1(0.,AJ2+DJ2)	CAP1	388
	IF (F11 .LT. DFCR1) GO TO 600	CAP1	389
	IF (DEBUG1 .EQ. 1)	CAP1	390
	1PRINT 1390,NCAP,AJ1,AJ2,F11	CAP1	391
1390	FORMAT (* 390 SKIP TO JOINT, NCAP=*13,* J1,J2,F11=*1P3E10.3)	CAP1	392
	GO TO 418	CAP1	393
C		CAP1	394
C	YIELD AT JOINT OF CAP AND MOHR-COULOMB	CAP1	395
C		CAP1	396
400	IF (IH .NE. 8) GO TO 350	CAP1	397
	CRIT=(AJ2T-AJ20)*W2(M)*BK*AJ10	CAP1	398
	CRIT2=(AJ1T-AJ10)*BG*AJ20	CAP1	399
	IF (DEBUG1 .EQ. 1)	CAP1	400
	1PRINT 1405,CRIT,CRIT2,AJ10,AJ20	CAP1	401
1405	FORMAT (* 405 CRIT,CRIT2=*1P2E10.3,* AJ10,AJ20=*2E10.3)	CAP1	402
	IF (CRIT .GT. CRIT2) GO TO 350	CAP1	403
410	DF11=-AMC2(M)/AMC3(M)*EXP(AJ11/AMC3(M))-AMC4(M)/AMC5(M)*EXP(AJ11/	CAP1	404
	1 AMC5(M))	CAP1	405
	DF21=2./9.*AJ11	CAP1	406
	DF22=2.*AJ21/W2(M)	CAP1	407
	DET=9.*BK*(DF11*DF22-DF21)*DPDE	CAP1	408
	AJ1=-DPDE*(AJ1T-AJ10)/DET + AJ10	CAP1	409
	AJ2=DPDE*DF11*(AJ1T-AJ10)/DET + AJ20	CAP1	410
	AJ2=AMAX1(0.,AJ2)	CAP1	411
	IF (DEBUG1 .EQ. 1)	CAP1	412
	1PRINT 1908,AJ1,AJ2,AJ10,AJ20,DF11,DF21,DF22,DPDE	CAP1	413
1908	FORMAT(* JOINT 418 - AJ1,AJ2,AJ10,AJ20 =*,1P4E10.3/	CAP1	414
	1 * DF11,DF21,DF22,DPDE =*,4E10.3)	CAP1	415
	DEP=DEVT-(AJ1-AJ10)/(3.*BK)	CAP1	416
418	NMC=0	CAP1	417
420	NMC=NMC+1	CAP1	418
	IH=8	CAP1	419
	TAU2=TAU3=0.	CAP1	420
	IF (AJ1 .LT. -10.*AMAX1(AMC3(M),AMC5(M))) GO TO 430	CAP1	421
	AJJ=AJ1	CAP1	422
	IF (AJ1 .GT. AMC6(M)) AJJ=AMC6(M)	CAP1	423
	TAU2=AMC2(M)*EXP(AJJ/AMC3(M))	CAP1	424
	TAU3=AMC4(M)*EXP(AJJ/AMC5(M))	CAP1	425
430	AJ2 =AMC1(M)+TAU2+TAU3	CAP1	426
	AJ2=AMAX1(0.,AJ2)	CAP1	427
	XI1=TAU2/AMC3(M)+TAU3/AMC5(M)	CAP1	428
	XI2=TAU2/AMC3(M)**2+TAU3/AMC5(M)**2	CAP1	429
	DZEP=DEVT-(AJ1-AJ10)/(3.*BK)	CAP1	430
	ZEP=ZEPV+AMIN1(0.,DZEP)	CAP1	431
	CALL CAPPR(PR,ZEP,M,D,IH,YM)	CAP1	432
	IF (IH .EQ. 9) GO TO 480	CAP1	433
	YM=YM/(3.*BK)	CAP1	434
	IF (ABS(SQRT(AJ1**2/9.+AJ2**2/W2(M))+PR) .LT. DFCR1) GO TO 600	CAP1	435
475	DJ=0.5*(AJ2 **2/W2(M)+AJ1**2/9.-PR**2)/(-AJ2 *XI1/W2(M)-AJ1/9.+	CAP1	436
	1 PR*YM)	CAP1	437
	DJA=DJ	CAP1	438
	AAA=(XI2*DJ)**2/W2(M)+2.*XI1*XI2*DJ/W2(M)+XI1**2/W2(M)+2.*AJ2*XI2	CAP1	439
	1 /W2(M)+0.11111-YM**2	CAP1	440
	BBB=2.*(AJ2 *XI1/W2(M)+AJ1/9.-PR*YM)	CAP1	441
	CCC=AJ2 **2/W2(M)+AJ1**2/9.-PR**2	CAP1	442
	IF (BBB**2-4.*AAA*CCC .GT. 0.)	CAP1	443
	1DJ=0.5*BBB/AAA*(SQRT(1.-4.*AAA*CCC/BBB**2)-1.)	CAP1	444
	AJ1=AMIN1(AJ10,AJ1+DJ)	CAP1	445
	CRIT=SQRT(AJ2**2/W2(M)+AJ1**2/9.)	CAP1	446
	IF (DEBUG1 .EQ. 1)	CAP1	447
	1PRINT 1480,AJ1,DJ,DJA,AJ2,CRIT,PR,AAA,BBB,CCC	CAP1	448
1480	FORMAT (* 480 AJ1,DJ,DJA=*1P3E10.3,* AJ2,CRIT,PR=*3E10.3,	CAP1	449
	1 * AAA,BBB,CCC=*3E10.3)	CAP1	450
	IF(NMC.GE. 5) GO TO 700	CAP1	451

SUBROUTINE CAP1 (Continued)

	IF(NMC.GT.1) GO TO 420	CAP1	452
	BK=BKK(AJ1,AJ10)	CAP1	453
	BG=GG(AJ2,AJ20)	CAP1	454
	GO TO 420	CAP1	455
480	AJ1=3.*PR	CAP1	456
	AJ2=AMIN1(AJ2,AMC1(M))	CAP1	457
	GO TO 600	CAP1	458
C	*****	*****	CAP1
C	COMPLETION OF STRESS CALCULATION FOR ELASTIC CASE	CAP1	459
500	AJ1=AJ1T	CAP1	460
	P=AJ1/3.	CAP1	461
	SX=SX-P0+2.*BG*(EX*RR-DEVT/3.)+P	CAP1	462
	SY=SY-P0+2.*BG*(EY*RR-DEVT/3.)+P	CAP1	463
	SZ=AJ1-SX-SY	CAP1	464
	SXY=SXY+2.*BG*EXY*RR	CAP1	465
	AJ2=AJ2T	CAP1	466
	IH=5	CAP1	467
	GO TO 630	CAP1	468
C	*****	CAP1	469
C	TENSILE FAILURE ON THE MOHR-COULOMB SURFACE	CAP1	470
550	AJ1=AMIN1(AJ1T,AMC6(M))	CAP1	471
	AJ2=AMC1(M)+AMC2(M)*EXP(AJ1/AMC3(M))+AMC4(M)*EXP(AJ1/AMC5(M))	CAP1	472
	P=AJ1/3.	CAP1	473
	SXD=SX-P0+2.*BG*(EX-ZEVT/3.)*RR	CAP1	474
	SYD=SY-P0+2.*BG*(EY-ZEVT/3.)*RR	CAP1	475
	SZD=SZ-P0+2.*BG*(EZ-ZEVT/3.)*RR	CAP1	476
	SXYD=SXY+2.*BG*EXY*RR	CAP1	477
	AJ2T=SQRT(0.5*(SXD**2+SYD**2+SZD**2)+SXYD**2)	CAP1	478
	FAC=AJ2/AMAX1(1.,AJ2T)	CAP1	479
	SX=SXD*FAC+P	CAP1	480
	SY=SYD*FAC+P	CAP1	481
	SZ=SZD*FAC+P	CAP1	482
	SXY=SXYD*FAC	CAP1	483
	DEPT=SQRT((EX**2+EY**2+EZ**2)/2.+EXY**2)*RR*(AJ2T-AJ2)/	CAP1	484
1	(AJ2T+1.)	CAP1	485
	IF (TEVP.EQ. -1.) TEVP=0.	CAP1	486
	TEVP=TEVP+DEPT	CAP1	487
	IH=6	CAP1	488
	SMAX=AMAX1((SX+SY+SQRT(4.*SXY**2+(SX-SY)**2))/2.,SZ)	CAP1	489
	IF (TEVP.GT. DAMG(M).AND. SMAX.GE. SCRIT(M).AND. AJ1.GE. 0.)	CAP1	490
1	GO TO 570	CAP1	491
	ZEVP=ZEVP+AMIN1(0.,ZEVT*RR-(AJ1-AJ10)/BK/3.)	CAP1	492
	GO TO 630	CAP1	493
570	CONTINUE	CAP1	494
	ENU=(3.-2.*BG/BK)/(6.+2.*BG/BK)	CAP1	495
	EMOD=2.*(1.+ENU)*BG	CAP1	496
	DEX=(SX-ENU*(SY+SZ))/EMOD	CAP1	497
	DEY=(SY-ENU*(SX+SZ))/EMOD	CAP1	498
	DEZ=(SZ-ENU*(SX+SY))/EMOD	CAP1	499
	DEXY=SXY/2./BG	CAP1	500
	DEPF=SQRT((DEX**2+DEY**2+DEZ**2)/2.+DEXY**2)	CAP1	501
	IF (TEVP.EQ. -1.) TEVP=0.	CAP1	502
	TEVP=TEVP+DEPF+(1.-RSUM)/RR*DEPT	CAP1	503
580	SX=0.	CAP1	504
	SY=0.	CAP1	505
	SZ=0.	CAP1	506
	SXY=0.	CAP1	507
	AJ1=0.	CAP1	508
	AJ2=0.	CAP1	509
	D=DH	CAP1	510
	RR=1.-RSUM	CAP1	511
	ZEVP=ZEVP+AMIN1(0.,ZEVT*RR-(AJ1-AJ10)/AK(M)/3.)	CAP1	512
	IF (IH.NE. 10) PRINT 1590,K,J,N	CAP1	513
1590	FORMAT (22H SEPARATION AT CELL K=I3,H4,J=I3,9H ON CYCLEI4)	CAP1	514
	IH=10	CAP1	515
	GO TO 630	CAP1	516
C	*****	*****	CAP1
C	COMPUTE STRESSES AT END OF ITERATIONS	CAP1	517
600	CONTINUE	CAP1	518
	AJ2=AMAX1(0.,AJ2)	CAP1	519
	DEP=DEVT-(AJ1-AJ10)/(3.*BK)	CAP1	520
	ZEVP=ZEVP+AMIN1(0.,DEP)	CAP1	521
	P=AJ1/3.	CAP1	522
	EV=(EX+EY+EZ)/3.	CAP1	523
	SXD=SX-P0+2.*BG*(EX-EV)*RR	CAP1	524
		CAP1	525
		CAP1	526

SUBROUTINE CAP1 (Concluded)

SYD=SY-P0+2.*BG*(EY-EV)*RR	CAP1	527
SZD=SZ-P0+2.*BG*(EZ-EV)*RR	CAP1	528
SXYD=SXY+2.*BG*EXY*RR	CAP1	529
AJ2T=SQRT(0.5*(SXD**2+SYD**2+SZD**2)+SXYD**2)	CAP1	530
FAC=AJ2/AMAX1(1.,AJ2T)	CAP1	531
SX=SXD*FAC+P	CAP1	532
SY=SYD*FAC+P	CAP1	533
SZ=SZD*FAC+P	CAP1	534
SXY=SXYD*FAC	CAP1	535
C *****	*****	CAP1
C PREPARE FOR NEXT SUBCYCLE	CAP1	536
630 CONTINUE	CAP1	537
RSUM=RSUM+RR	CAP1	538
IF (DEBUG1.EQ.1) PRINT 1630,K,J,RR,RSUM,SX,SY,SZ,SXY,AJ1,AJ2,D,	CAP1	539
1 DOLD,IH,ZEVT,ZEIT,ZEVP,TEVP	CAP1	540
1630 FORMAT (* --FINAL--K,J=*2I3,* RR,RSUM=*2F8.5,* SX,SY,SZ,SXY=*2	CAP1	541
1 1P4E10.3,/4X,* AJ1,AJ2=*2E13.6,* D,DOLD=*0P2F10.6,* IH=*I2,	CAP1	542
2 * ZEVT,ZEIT,ZEVP,TEVP=*1P4E10.3)	CAP1	543
IF(1.-RSUM.LT.1.E-10) RETURN	CAP1	544
IF (ABS(AJ1T-AJ10) .GT. 1.) EPRAT1=AMAX1(-1.,AMIN1(1.,	CAP1	545
1 (AJ1-AJ10)/(AJ1T-AJ10)))	CAP1	546
IF (ABS(AJ2T-AJ20) .GT. 1.) EPRAT2=AMAX1(-1.,AMIN1(1.,	CAP1	547
1 (AJ2-AJ20)/(AJ2T-AJ20)))	CAP1	548
RR=AMIN1(1.-RSUM,1.3*RR)	CAP1	549
DOLD=D	CAP1	550
IF (NINC .LT. NMAX) GO TO 200	CAP1	551
PRINT 1630,K,J,RR,RSUM,SX,SY,SZ,SXY,AJ1,AJ2,D,DOLD,IH,ZEVT,	CAP1	552
1 ZEIT,ZEVP,TEVP	CAP1	553
PRINT 1650,NINC	CAP1	554
1650 FORMAT (* STOP CALLED FOR NMAX=NINC=*I4)	CAP1	555
STOP 3121	CAP1	556
C *****	*****	CAP1
C CUT STRAIN INCREMENT AND RESTART	CAP1	557
C	CAP1	558
700 RR=0.5*RR	CAP1	559
NRE=NRE+1	CAP1	560
IF(NRE.GE.1) PRINT 1700,NRE,N,K,J,DH,DOLD,DORG,RR,SX,SY,SZ,SXY,	CAP1	561
2 EX,EY,EZ,EXY,ZEVP,TEVP,IH,AJ1,AJ2,F11,F21,AJ10,AJ20,F10,F20,	CAP1	562
2 F1T,F2T,DPDE	CAP1	563
EPRAT1=EPRAT2=0.1	CAP1	564
IF(NRE.GE.10) STOP 3120	CAP1	565
GO TO 200	CAP1	566
C *****	*****	CAP1
1020 FORMAT (4(2A5,E10.3))	CAP1	567
1021 FORMAT (1H+,80X,3HIN=I2,4H CAP)	CAP1	568
1022 FORMAT (2A5,7E10.3)	CAP1	569
1024 FORMAT (2A5,I10,2A5,I10,2A5,E10.3,2A5,E10.3)	CAP1	570
1040 FORMAT (4(2A5,1PE10.3))	CAP1	571
1042 FORMAT (2A5,1P7E10.3)	CAP1	572
1044 FORMAT (2A5,I10,2A5,I10,2A5,1PE10.3,2A5,E10.3)	CAP1	573
1700 FORMAT (* RESTART WITH NRE,N,K,J=* I2,I5,2I3,* DH,DOLD,DORG,RR=*2	CAP1	574
1 4F15.10/* SX,SY,SZ,SXY=*1P4E10.3,* EX,EY,EZ,EXY=*4E10.3/	CAP1	575
2 *ZEVP,TEVP,IH=*2E10.3,I5,* AJ1,AJ2=*2E10.3,* F11,F21=*2E10.3	CAP1	576
3 /* AJ10,AJ20,F10,F20=*4E10.3,* F1T,F2T,DPDE=*3E10.3)	CAP1	577
END	CAP1	578
	CAP1	579
	CAP1	580
	CAP1	581

SUBROUTINE CAPPR

	SUBROUTINE CAPPR(P,EP,M,D,IH,YM)	CAP1	582
C		CAP1	583
	COMMON /EQS/EQSTC(6),EQSTD(6),EQSTE(6),EQSTG(6),EQSTH(6),EQSTN(6),	CAP1	584
	1 EQSTS(6),RH0(6),RH0S(6),YC(6),YAD(6),MU(6),ESC(6,20),CLIN,CQSQ,	CAP1	585
	2 TRIQ,AMAT(6,4),SP(6),G2(6),PMIN(6)	CAP1	586
	COMMON /POR/ PORA(6,5),PORB(6,5),PORC(6,5),EVP(6,5)	CAP1	587
C		CAP1	588
	P=PORA(M,1)	CAP1	589
	IF (EP .GE. -1.E-6) GO TO 145	CAP1	590
	NC=5	CAP1	591
	IF (EP .LT. EVP(M,5)) GO TO 130	CAP1	592
	NC=0	CAP1	593
125	NC=NC+1	CAP1	594
	IF (EP .LT. EVP(M,NC)) GO TO 125	CAP1	595
130	P=(PORA(M,NC)+(PORB(M,NC)+PORC(M,NC)*EP)*EP)	CAP1	596
	YM=-(PORB(M,NC)+2.*EP*PORC(M,NC))	CAP1	597
	IF (D .LT. RH0S(M)) GO TO 145	CAP1	598
	EMU=D/RH0S(M)-1.	CAP1	599
	PS=EMU*(EQSTC(M)+EMU*(EQSTD(M)+EMU*EQSTS(M)))	CAP1	600
	IF (PS .LT. -P) GO TO 145	CAP1	601
	YM=-D*EQSTC(M)/RH0S(M)	CAP1	602
	P=-PS	CAP1	603
	IH=9	CAP1	604
145	RETURN	CAP1	605
	END	CAP1	606

SUBROUTINE DEPOS

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C      SUBROUTINE DEPOS(NPART,IN)
C
C      THIS ROUTINE USED WITH SRI GENRAT.
C      CALLED BY GENRAT FOR RADIATION DEPOSITION CALCULATIONS.
C      ROUTINE IS SEPARATED INTO 3 PARTS BY INDICATOR, NPART, TO
C      1 READ DATA ON MATERIAL ABSORPTION PROPERTIES
C      2 READ SPECTRUM AND DEPOSIT ENERGY INTO SS ARRAY.
C      3 PRINT OUT COORDINATE ARRAYS IN DEPOSITION EDIT
C      INPUT -
C      * TWO FORMAL PARAMETERS
C      * READS ABSORPTION SPECTRA, RADIATED SPECTRA FROM CARDS.
C      OUTPUT -
C      * FILLS SS ARRAYS.
C      * SETS *SSTOPM*, *JSTAR*, *NSPEC*.
C      * WRITES DEPOSITION EDIT.
C      THIS IS A VERSION MODIFIED TO ACCEPT THE ABSORPTION COEFFICIENT
C      DATA DIRECTLY FROM FSCATT.
C
C      INTEGER H,POROUS,PRESS,RINTER,SOLID,SPALL
C      REAL MATL,NEM,NET,NEMH,NETH
C      MISCELLANEOUS
C      COMMON AZERO(1),CEF,CKS,DAVG,DELTIM,DISCPT(10),DOLD,DRHO,DTMAX,
1      DTMIN,DTN,DTNH,DU,DX,EOLD,F,FAC,FIRST,J,JCYCS,JINIT,
2      JFIN,JREZON(15),JSMAX,JSTAR,JTS,LSUB(3D),M,MAXPR(3D),N,NCYCS,
3      NEDIT,NPERN,NR,NREZON,NSCRB(6),NSEPRAT,NSPALL,NTEDT,
4      NTEX,NTR(15),POLD,P6(20),R(3D),RLAST,SLAST,SMAX,TEDIT(5D),
5      TF,TIME,TJ,TREZON,TS,T6(20),ULAST,UOLD,UZERO,XLAST,XNOW,XOLD
1      ,XJDIT(20),MS
C      HALFSTEP VALUES
C      COMMON DH,DHLAST,DUH,EH,PH,RH,RHLAST,SH,SHLAST,UH,UHLAST,XH,XHLAST
1      ,NEMH,NETH
C      CONDITION INDICATORS
C      COMMON INF,LINTER,MIRROR,NORMAL,POROUS,PRESS,RINTER,SOLID,SPALL
C      CELL LAYOUT
C      COMMON DXX(3D),JBND(30),JMAT(3D),NAUTO,MATL(6,2),NLAYER,NMTRLS,
1      THK(30)
C      COORDINATE ARRAYS
C      COMMON/COORD/X(20D),XD(20D),CHL(20D),DHL(20D),DPDD(20D),DPDE(20D),
1      EHL(20D),H(20D,3),NEM(20D),NET(20D),PHL(20D),RHL(20D),SDT(20D),
2      SHL(20D),T(20D),U(20D),YHL(20D),ZHL(20D)
C      COMMON/NSC/A(5DDD)
C      NAMED COMMON
C      REAL MU,MUM
C      COMMON /EQS/ EQSTA(6),EQSTC(6),EQSTD(6),EQSTE(6),EQSTG(6),
1      EQSTH(6),EQSTN(6),EQSTS(6),EQSTV(6),CZQ(6),CWQ(6),C2(6)
C      COMMON /MELT/ EMELT(6,8),GMELT(6,8),SPH(6),THERM(6,8)
C      COMMON /RHO/ RH0(6),RHOS(6)
C      COMMON /TSR/ TSR(6,3D),EXMAT(6,20),TENS(6,3)
C      COMMON /Y/ YD(6),YADD(6),MU(6),MUM,YADDM
C      COMMON /IND/ IEOS(6),INDK(2D),NALPHA,NCMP(6),NFR(6),NFOR(6),
1      NDS(6),NPR(6),NCON(6),NVAR(6)
C      COMMON /RAD/ SSTOP(9),START(9),SDURM,SSTOPM,NSPEC,SSJ,JSS,IPL0T(4)
1      ,XMAX(4),XMIN(4),YMAX(4),YMIN(4),IA(7),ITITLE(24),NARZ,TARZ
C      COMMON/SS/SS(5DD)
C      COMMON /PES/ LVMAX,LVTOT,LVAR(20D),COM(4000)
C
C      DIMENSION AC(109),AAD(6,6,1D),AA1(6,6,10),AA2(6,6,10),AA3(6,6,1D),
1      EDGE(6,6,10),EI(1D9),RHOC(6,6),TBL(1D9),NOE(6,6),IVAR(8),
2      ATWT(6,6),BBDY(100),PBW(6),NAME(6),EIBB(10D)
C      DIMENSION DELX(20D),EPGJ(20D),PCT(20D),CPG(20D),TC(20D),P(20D),
1      DIMPMCC(20D),FRONT(5,3D),XPL(20D),YPL(20D),EABS(20D)
C      DIMENSION ANGLE(3D)
C
C      EQUIVALENCE(A(2D1),AC),(A(31D),AAD),(A(670),AA1),(A(1D3D),AA2),
1      (A(139D),AA3),(A(175D),EDGE),(A(211D),EI),(A(2219),RHOC),
2      (A(2255),TBL),(A(2364),NOE),(A(240D),ATWT)
C      EQUIVALENCE(DELX,A),(EPGJ,A(2D1)),(PCT,A(401)),(CPG,A(6D1)),
1      (TC,A(8D1)),(P,A(1DD1)),(DIMPMCC,A(1201)),(XPL,A(14D1)),
2      (YPL,A(16D1)),(EABS,A(1801))
C
C      DATA BBDY/.D1,.D3,.D5,.D7,.D9,.15,.25,.35,.45,.55,.65,.75,
1      1.85,.95,1.D5,1.15,1.25,1.35,1.45,1.55,1.65,1.75,1.85,1.95,2.05,
2      22.15,2.25,2.35,2.45,2.55,2.65,2.75,2.85,2.95,3.05,3.15,3.25,
3      33.35,3.45,3.55,3.65,3.75,3.85,3.95,4.D5,4.15,4.25,4.35,4.45,
DEPOS 2
DEPOS 3
DEPOS 4
DEPOS 5
DEPOS 6
DEPOS 7
DEPOS 8
DEPOS 9
DEPOS 10
DEPOS 11
DEPOS 12
DEPOS 13
DEPOS 14
DEPOS 15
DEPOS 16
DEPOS 17
DEPOS 18
DEPOS 19
PUFCOM 2
PUFCOM 3
PUFCOM 4
PUFCOM 5
PUFCOM 6
PUFCOM 7
PUFCOM 8
PUFCOM 9
PUFCOM 10
PUFCOM 11
PUFCOM 12
PUFCOM 13
PUFCOM 14
PUFCOM 15
PUFCOM 16
PUFCOM 17
PUFCOM 18
PUFCOM 19
PUFCOM 20
COORDCOM 2
COORDCOM 3
COORDCOM 4
COORDCOM 5
NSCCOM 2
EQSTCOM 2
EQSTCOM 3
EQSTCOM 4
EQSTCOM 5
EQSTCOM 6
EQSTCOM 7
EQSTCOM 8
EQSTCOM 9
INDCOM 2
INDCOM 3
RADCOM 2
RADCOM 3
SSCOM 2
DEPOS 27
DEPOS 28
DEPOS 29
DEPOS 30
DEPOS 31
DEPOS 32
DEPOS 33
DEPOS 34
DEPOS 35
DEPOS 36
DEPOS 37
DEPOS 38
DEPOS 39
DEPOS 40
DEPOS 41
DEPOS 42
DEPOS 43
DEPOS 44
DEPOS 45
DEPOS 46

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SUBROUTINE DEPOS (Continued)

44.55,4.65,4.75,4.85,4.95,5.05,5.15,5.25,5.35,5.45,5.55,5.65,	DEPOS	47
55.75,5.85,5.95,6.10,6.3,6.5,6.7,6.9,7.1,7.3,7.5,7.7,7.9,8.1,	DEPOS	48
68.3,8.5,8.7,8.9,9.1,9.3,9.5,9.7,9.9,10.5,11.5,12.5,13.5,14.5,15.5,	DEPOS	49
716.5,17.5,18.5,19.5,20.5,5*0.0/	DEPOS	50
DATA EIBB/4.076E-7,2.829E-6,7.604E-6,1.466E-5,2.393E-5,	DEPOS	51
13.312E-4,8.555E-4,1.582E-3,2.475E-3,3.498E-3,4.622E-3,5.818E-3,	DEPOS	52
27.057E-3,8.330E-3,9.595E-3,1.085E-2,1.208E-2,1.326E-2,1.438E-2,	DEPOS	53
31.544E-2,1.644E-2,1.736E-2,1.819E-2,1.893E-2,1.960E-2,2.017E-2,	DEPOS	54
42.067E-2,2.106E-2,2.138E-2,2.163E-2,2.178E-2,2.187E-2,2.188E-2,	DEPOS	55
52.183E-2,2.172E-2,2.155E-2,2.132E-2,2.105E-2,2.073E-2,2.037E-2,	DEPOS	56
61.998E-2,1.956E-2,1.910E-2,1.863E-2,1.814E-2,1.763E-2,1.711E-2,	DEPOS	57
71.657E-2,1.603E-2,1.549E-2,1.495E-2,1.440E-2,1.387E-2,1.332E-2,	DEPOS	58
81.279E-2,1.227E-2,1.176E-2,1.125E-2,1.076E-2,1.027E-2,9.800E-3,	DEPOS	59
99.350E-3,8.910E-3,8.470E-3,1.572E-2,1.417E-2,1.274E-2,1.142E-2,	DEPOS	60
1.021E-2,9.110E-3,8.100E-3,7.200E-3,6.370E-3,5.640E-3,4.970E-3,	DEPOS	61
4.380E-3,3.850E-3,3.380E-3,2.960E-3,2.510E-3,2.350E-3,1.980E-3,	DEPOS	62
1.730E-3,1.500E-3,5.008E-3,2.425E-3,1.147E-3,5.322E-4,2.429E-4,	DEPOS	63
1.092E-4,4.852E-5,2.131E-5,9.269E-6,3.996E-6,2.960E-6,5*0./	DEPOS	64
C	DEPOS	65
2 FORMAT(1H+,79X,5H IND=A2,5H, IN=I2,9H -DEPOS-)	DEPOS	66
3 FORMAT(1H+,103X,* ANGLE FROM NORMAL(DEG)*)	DEPOS	67
4 FORMAT(1H+,103X*, , ,CAL/CM2,SEC,SEC*)	DEPOS	68
5 FORMAT(1H+,103X*,CM,ERG/G*)	DEPOS	69
10 FORMAT(A1,A9,A5,A2,I3,3(A10,E10.3))	DEPOS	70
11 FORMAT(4(A10,1PE10.3))	DEPOS	71
14 FORMAT (*1*,10A10/3X,*J*,9X,*X*,9X,*X*,2(5X,*DEPOS*),	DEPOS	72
1 3X,*PCT TR.*,5X,*TEMP.*,4X,*PRESS.*,3X,*IMPULSE*,5X,*MATERIAL*4X,	DEPOS	73
2*COND*6X,*J*,8X,*DX*2X,*ABSORBED*/10X,*INCH*8X,*CM*3X,*ERGS/GM*,4X,	DEPOS	74
3 ,*CAL/GM*,14X,*DEG. C*,6X,*KBAR*,5X,*KTAPS*,36X,*CM*3X,*CAL/CM2*)	DEPOS	75
15 FORMAT(14,2F10.6,1P2E10.3,F10.3,1P3E10.3,3X,A9,3X,3R2,2X,I5,1PE10.	DEPOS	76
13,F10.3)	DEPOS	77
54 FORMAT(A10,I10,A7,A3,1P5E10.3)	DEPOS	78
55 FORMAT(A1,A9,A8,I2,A10,F10.7)	DEPOS	79
56 FORMAT(A1,A9,2A10,I10,A10,F10.3)	DEPOS	80
57 FORMAT(1P8E10.3)	DEPOS	81
70 FORMAT(*O*8X,*YIELD=*1PE10.3,* SOUND SP=*1PE10.3,* DENSITY=*1	DEPOS	82
1 1PE10.3,* TENS STR=*1PE10.3,* INTERFACE STRENGTH=*1PE10.3/)	DEPOS	83
72 FORMAT(10X,*DEPOS - CONST. DENSITIES (G/CM3), RHOC=*1P6E10.3)	DEPOS	84
73 FORMAT(10X,*DEPOS - ESUM=*1PE10.3,* CAL/CM2*)	DEPOS	85
74 FORMAT(* TOTAL ENERGY ABSORBED IS*1PE12.3,* CAL/CM2*)	DEPOS	86
75 FORMAT (A1,A9,2A10,I10,4A10)	DEPOS	87
76 FORMAT(* TOTAL ENERGY ABSORBED IS*1PE12.3,* CAL/CM*)	DEPOS	88
77 FORMAT(* TOTAL ENERGY ABSORBED IS*1PE12.3,* CAL*)	DEPOS	89
80 FORMAT(A7,1P4E13.5)	DEPOS	90
81 FORMAT(7X,1P4E13.5)	DEPOS	91
82 FORMAT (* ERROR IN MCCLOSKEY INTEGRAL FOR LAYER*I3*, X(J+1)=*	DEPOS	92
1 1PE10.3,* DID NOT LIE BETWEEN *1PE10.3,* AND *1PE10.3)	DEPOS	93
89 FORMAT(13X,E12.5,1X,E12.5,1X,E12.5,1X,E12.5)	DEPOS	94
92 FORMAT(4(2A5,1PE10.3))	DEPOS	95
93 FORMAT(A1,A9,2A10,1PE10.3,A10,1PE10.3)	DEPOS	96
C	DEPOS	97
240 GO TO (250,400,700) NPART	DEPOS	98
C *****	DEPOS	99
C ENTRY FOR READING MATERIAL ABSORPTION PARAMETERS	DEPOS	100
250 CONTINUE	DEPOS	101
NCONST=NCON(M)	DEPOS	102
NNOE=10H X-RAY ABS	DEPOS	103
IDD=1H \$ IN5=5	DEPOS	104
D0 260 NC=1,NCONST	DEPOS	105
READ (IN,55)A1,NAME(NC),A2,ITAPE,A3,PBW(NC)	DEPOS	106
WRITE (6,55)A1,NAME(NC),A2,ITAPE,A3,PBW(NC)	DEPOS	107
WRITE (6,2) IDD,IN	DEPOS	108
INL=IN	DEPOS	109
IF (ITAPE.EQ. 0) GO TO 255	DEPOS	110
INL=ITAPE	DEPOS	111
CALL REDR(NAME(NC),NNOE,INL,2)	DEPOS	112
125 READ (INL,56)A1,NAME(NC),A2,A3,NOE(M,NC),A4,ATWT(M,NC)	DEPOS	113
WRITE (6,56)A1,NAME(NC),A2,A3,NOE(M,NC),A4,ATWT(M,NC)	DEPOS	114
WRITE (6,2) IDD,INL	DEPOS	115
NOED=NOE(M,NC) \$ NOE1=NOED+1	DEPOS	116
READ (INL,89) (EDGE(M,NC,ND),ND=1,NOED)	DEPOS	117
FN=7H EDGE	DEPOS	118
WRITE (6,80)FN,(EDGE(M,NC,ND),ND=1,NOED)	DEPOS	119
WRITE (6,2) IDD,INL	DEPOS	120
READ (INL,89) (AA0(M,NC,ND),AA1(M,NC,ND),AA2(M,NC,ND),	DEPOS	121

SUBROUTINE DEPOS (Continued)

1	AA3(M,NC,ND),ND=1,N0ED)	DEPOS	122
	FN=7H COEFS	DEPOS	123
	WRITE(6,80) FN,AA0(M,NC,1),AA1(M,NC,1),AA2(M,NC,1),AA3(M,NC,1)	DEPOS	124
	IF (N0ED .EQ. 1) GO TO 258	DEPOS	125
	WRITE(6,81) (AA0(M,NC,ND),AA1(M,NC,ND),AA2(M,NC,ND),AA3(M,NC,ND),	DEPOS	126
	1 ND=2,N0ED)	DEPOS	127
258	WRITE(6,2)IDD,INL	DEPOS	128
260	CONTINUE	DEPOS	129
	WTOT=1.	DEPOS	130
	IF (NCONST .EQ. 1 .OR. PBW(1) .LT. 1.) GO TO 280	DEPOS	131
	WTOT=0.	DEPOS	132
	DO 270 NC=1,NCONST	DEPOS	133
	PBW(NC)=PBW(NC)*ATWT(M,NC)	DEPOS	134
270	WTOT=WTOT+PBW(NC)	DEPOS	135
280	DO 290 NC=1,NCONST	DEPOS	136
290	RHOC(M,NC)=RH0(M)*PBW(NC)/WTOT	DEPOS	137
	IF (NCONST .EQ. 1) RHOC(M,1)=RH0(M)	DEPOS	138
	WRITE(6,72) (RHOC(M,NC),NC=1,NCONST)	DEPOS	139
	RETURN	DEPOS	140
C	*****	DEPOS	141
C	ENTRY FOR DEPOSITING RADIATION IN THE SS ARRAY	DEPOS	142
400	READ (5,54) A1,NSPEC,N2,A2,(ANGLE(NL),NL=1,5)	DEPOS	143
	WRITE(6,54) A1,NSPEC,N2,A2,(ANGLE(NL),NL=1,5)	DEPOS	144
	WRITE(6,2) IND,IN5 \$ WRITE(6,3)	DEPOS	145
	IF (N2 .EQ. 7H ANGLES) GO TO 402	DEPOS	146
	DO 401 NL=2,NLAYER	DEPOS	147
401	ANGLE(NL)=ANGLE(1)	DEPOS	148
	GO TO 403	DEPOS	149
402	IF (NLAYER .LE. 5) GO TO 403	DEPOS	150
	READ (5,57) (ANGLE(NL),NL=6,NLAYER)	DEPOS	151
	WRITE(6,57) (ANGLE(NL),NL=6,NLAYER)	DEPOS	152
	WRITE(6,2) IND,IN5 \$ WRITE(6,3)	DEPOS	153
403	DO 404 NL=1,NLAYER	DEPOS	154
	FRONT(1,NL)=FRONT(2,NL)=FRONT(3,NL)=FRONT(4,NL)=FRONT(5,NL)=0.	DEPOS	155
404	ANGLE(NL)=COS(ANGLE(NL)/57.2957795)	DEPOS	156
C	BEGIN LOOP OVER EACH SPECTRUM	DEPOS	157
	TOTCAL=0.	DEPOS	158
	DO 4040 I=1,500	DEPOS	159
4040	SS(I)=0.	DEPOS	160
	DO 485 NS=1,NSPEC	DEPOS	161
	JFINNS=JFIN*(NS-1)	DEPOS	162
	IN=5	DEPOS	163
	IDD=5H	DEPOS	164
C	INDICATOR IN COLUMNS 11 THROUGH 15 SHOWS SPECTRUM TYPE	DEPOS	165
C	5H NHNU = ARBITRARY SPECTRUM	DEPOS	166
C	5H NBB = SERIES OF BLACK BODIES (NBB OF THEM)	DEPOS	167
C	5H NARB = DEPOSITION FROM SCATT PROGRAM	DEPOS	168
	READ(5,10) IND,SPECNAM,A1,A2,NHNU,A3,ECAL,A4,START(NS),A5,	DEPOS	169
1	SSTOP(NS)	DEPOS	170
	WRITE(6,10)IDD,SPECNAM,A1,A2,NHNU,A3,ECAL,A4,START(NS),A5,	DEPOS	171
1	SSTOP(NS)	DEPOS	172
	WRITE(6,2) IND,IN5 \$ WRITE(6,4)	DEPOS	173
	NARB=NBB=NHNU	DEPOS	174
	IF (IND .EQ. IDD) GO TO 405	DEPOS	175
	IN=4	DEPOS	176
	CALL REDR(SPECNAM,IDD,IN,1)	DEPOS	177
405	CONTINUE	DEPOS	178
	SSTOPM=AMAX1(SSTOPM,SSTOP(NS))	DEPOS	179
	IF (A1 .EQ. 5H NARB) GO TO 465	DEPOS	180
	IF (A1 .EQ. 5H NBB) GO TO 420	DEPOS	181
	NRAD=1 \$ TEMP=1.	DEPOS	182
C	ARBITRARY SPECTRUM INPUT	DEPOS	183
	READ (IN,75)A1,SPECNAM,A2,A3,NHNU,(IVAR(1),I=1,4)	DEPOS	184
	WRITE(6,75)A1,SPECNAM,A2,A3,NHNU,(IVAR(1),I=1,4)	DEPOS	185
	WRITE(6,2) IDD,IN	DEPOS	186
	IF (IVAR(1) .NE. IDD) GO TO 412	DEPOS	187
	DO 410 NH=1,NHNU	DEPOS	188
	READ (IN,11) A1,TBL(NH),A2,EI(NH),A3	DEPOS	189
410	WRITE(6,11) A1,TBL(NH),A2,EI(NH),A3	DEPOS	190
	WRITE(6,2) IDD,IN	DEPOS	191
	GO TO 415	DEPOS	192
412	READ (IN,IVAR)(TBL(NH),EI(NH),NH=1,NHNU)	DEPOS	193
	WRITE(6,IVAR)(TBL(NH),EI(NH),NH=1,NHNU)	DEPOS	194
	WRITE(6,2) IDD,IN	DEPOS	195
	ESUM = 0.	DEPOS	196

SUBROUTINE DEPOS (Continued)

	D0 413 NH = 1, NHNU	DEPOS	197
413	ESUM = ESUM+EI(NH)	DEPOS	198
415	D0 417 NH=1, NHNU	DEPOS	199
417	EI(NH) = EI(NH)*ECAL/ESUM	DEPOS	200
	NR=1 \$ GO TO 430	DEPOS	201
C	BLACK BODY INPUT	DEPOS	202
420	NRAD=NBB \$ NHNU=95	DEPOS	203
	NR=1	DEPOS	204
424	READ (IN, 93) A1, SPECNAM, A2, A3, TEMP, A4, ECAL	DEPOS	205
	WRITE (6, 93) A1, SPECNAM, A2, A3, TEMP, A4, ECAL	DEPOS	206
	WRITE (6, 2) IDD, IN	DEPOS	207
	D0 428 NH=1, NHNU	DEPOS	208
	TBL(NH)=BBDY(NH)	DEPOS	209
428	EI(NH)=ECAL*EIBB(NH)	DEPOS	210
430	ESUM=0.	DEPOS	211
	D0 431 NH=1, NHNU	DEPOS	212
431	ESUM=ESUM+EI(NH)	DEPOS	213
	WRITE (6, 73) ESUM	DEPOS	214
C		DEPOS	215
C	COMPUTATION OF ABSORPTION COEFFICIENT - AC	DEPOS	216
	PERCNT=0.005*ECAL	DEPOS	217
	X(1)=0.	DEPOS	218
	XBNDM=0.	DEPOS	219
	DX2=50.	DEPOS	220
	JBEG=1	DEPOS	221
	D0 460 L=1, NLAYER	DEPOS	222
	M=JMAT(L)	DEPOS	223
	D0 432 I=1, 4	DEPOS	224
432	FRONT(I, L)=0.	DEPOS	225
	D0 433 NH=1, 109	DEPOS	226
433	AC(NH)=0.	DEPOS	227
	NCONST=NCON(M)	DEPOS	228
	D0 445 NC=1, NCONST	DEPOS	229
	NEDG=1	DEPOS	230
	D0 445 NH=1, NHNU	DEPOS	231
	ALNE=ALOG(TBL(NH)*TEMP)	DEPOS	232
	IF (TBL(NH)*TEMP .GE. 1.) GO TO 438	DEPOS	233
	AC(NH)=AC(NH)+RHOC(M, NC)*EXP(AAO(M, NC, 1)+ALNE*AA1(M, NC, 1))	DEPOS	234
	1 *(C.602252/ATWT(M, NC))/ANGLE(L)	DEPOS	235
	GO TO 444	DEPOS	236
438	IF (NEDG .GE. NGE(M, NC)) GO TO 440	DEPOS	237
	IF (EDGE(M, NC, NEDG+1) .GT. TBL(NH)*TEMP) GO TO 440	DEPOS	238
	NEDG=NEDG+1 \$ GO TO 438	DEPOS	239
440	AC(NH)=AC(NH)+RHOC(M, NC)*EXP(AAO(M, NC, NEDG)+ALNE*(AA1(M, NC, NEDG)	DEPOS	240
	1 +ALNE*(AA2(M, NC, NEDG)+ALNE*AA3(M, NC, NEDG)))*(C.602252/ATWT(M, NC	DEPOS	241
	2))/ANGLE(L)	DEPOS	242
444	CONTINUE	DEPOS	243
445	CONTINUE	DEPOS	244
C		DEPOS	245
C	DISTRIBUTE ENERGY INTO CELLS	DEPOS	246
	XBNDM=XBNDM+THK(L)	DEPOS	247
	JBNDM=JBND(L)-1	DEPOS	248
	J=JBEG	DEPOS	249
446	IF (J .GT. JBEG+1 .AND. XBNDM .EQ. 0.) GO TO 447	DEPOS	250
	DEP=0.	DEPOS	251
	D0 4461 NH=1, NHNU	DEPOS	252
4461	DEP=DEP+AC(NH)*EI(NH)	DEPOS	253
	IF (J .EQ. JBEG) GO TO 4462	DEPOS	254
	FRONT(4, L)=DEP/RHO(M)+FRONT(4, L)	DEPOS	255
	GO TO 447	DEPOS	256
4462	FRONT(1, L)=DEP/RHO(M)+FRONT(1, L)	DEPOS	257
	FRONT(3, L)=FRONT(1, L)*RHO(M)*EQSTG(M)*4.186E-2	DEPOS	258
	IF (SPH(M) .GT. 0.) FRONT(2, L)=FRONT(1, L)/SPH(M)+22.2	DEPOS	259
	DX1=DX2	DEPOS	260
447	IF (XBNDM .GT. 0.) GO TO 4481	DEPOS	261
	DX=X(J+1)-X(J)	DEPOS	262
	GO TO 449	DEPOS	263
4481	DX=ABS(PERCNT/DEP)	DEPOS	264
	IF (DX .GT. 1.05*DX1) DX=1.05*DX1	DEPOS	265
	IF (XBNDM .GT. X(J)+ DX) GO TO 448	DEPOS	266
	DX2=2.*DX	DEPOS	267
	DX=XBNDM-X(J)	DEPOS	268
	X(J+2) = XBNDM	DEPOS	269
	JBND(L)=J+1	DEPOS	270
	JBNDM=J	DEPOS	271

SUBROUTINE DEPOS (Continued)

448	X(J+1)=X(J)+DX	DEPOS	272
	DX1=DX	DEPOS	273
449	ESUM=0.	DEPOS	274
	DO 450 NH=1,NHNU	DEPOS	275
	IF (EI(NH) .LT. 1.E-20) GO TO 450	DEPOS	276
	EIZ=EI(NH)*(1.-EXP(-1.*AC(NH)*DX))	DEPOS	277
	EI(NH)=EI(NH)-EIZ	DEPOS	278
	ESUM=EIZ+ESUM	DEPOS	279
450	CONTINUE	DEPOS	280
	SS(JFINNS+J)=ESUM*4.186E7/RHO(M)/DX/(SSTOP(NS)-START(NS))*ANGLE(L)	DEPOS	281
1	+SS(JFINNS+J)	DEPOS	282
	TOTCAL=ESUM+TOTCAL	DEPOS	283
	IF (J .EQ. JBNDM) GO TO 460	DEPOS	284
	J=J+1	DEPOS	285
	GO TO 446	DEPOS	286
460	JBEG=JBND(L)+1	DEPOS	287
	IF (JFIN .GT. 0) GO TO 462	DEPOS	288
	JFIN=JBEG	DEPOS	289
	X(JFIN)=X(J+1)	DEPOS	290
462	JINIT=1	DEPOS	291
	NR=NR+1	DEPOS	292
	IF (NR-NRAD) 424,424,485	DEPOS	293
C	DEPOSITION FROM SCATT PROGRAM	DEPOS	294
465	ETOT=0.	DEPOS	295
	DO 483 L=1,NLAYER	DEPOS	296
	M=JMAT(L)	DEPOS	297
	RATIO = 1.	DEPOS	298
	IF (NARB .GE. 0) GO TO 466	DEPOS	299
	READ (5,11) A1,RHOLD	DEPOS	300
	WRITE (6,11) A1,RHOLD	DEPOS	301
	RATIO = RHOLD/RHO(M)	DEPOS	302
466	CONTINUE	DEPOS	303
	READ (IN,75) A1,SPECNAM,A2,A3,NPOINT, (IVAR(I),I=1,4)	DEPOS	304
	WRITE (6,75) A1,SPECNAM,A2,A3,NPOINT, (IVAR(I),I=1,4)	DEPOS	305
	WRITE (6,2) IDD,IN	DEPOS	306
	IF (NPOINT .EQ. 0) GO TO 483	DEPOS	307
	IF (IVAR(1) .NE. IDD) GO TO 475	DEPOS	308
	DO 470 NP=1,NPOINT	DEPOS	309
	READ (IN,92) A1,A2,TBL(NP),A3,A4,EI(NP)	DEPOS	310
470	WRITE (6,92) A1,A2,TBL(NP),A3,A4,EI(NP)	DEPOS	311
	WRITE (6,2) IDD,IN \$ WRITE (6,5)	DEPOS	312
	GO TO 476	DEPOS	313
475	READ (IN,IVAR)(TBL(NP),EI(NP),NP=1,NPOINT)	DEPOS	314
	WRITE (6,IVAR)(TBL(NP),EI(NP),NP=1,NPOINT)	DEPOS	315
	WRITE (6,2) IDD,IN \$ WRITE (6,5)	DEPOS	316
476	CONTINUE	DEPOS	317
	FRONT(1,L) = EI(1) * ECAL + FRONT(1,L)	DEPOS	318
	IF (SPH(M) .GT. 0.) FRONT(2,L)=FRONT(1,L)/SPH(M)+22.2	DEPOS	319
	FRONT(3,L)=FRONT(1,L)*RHO(M)*EQSTG(M)*4.186E-2	DEPOS	320
	J=1	DEPOS	321
	IF (L .GT. 1) J=JBND(L-1)+1	DEPOS	322
	IF (ABS(TBL(1)-X(J)) .LT. 1.E-10 .AND. RATIO .EQ. 1.) GO TO 478	DEPOS	323
	DX = X(J)-TBL(1)	DEPOS	324
	DO 477 I = 1, NPOINT	DEPOS	325
477	TBL(I)=(TBL(I)+DX-X(J))*RATIO+X(J)	DEPOS	326
478	CONTINUE	DEPOS	327
	XJP1=X(J+1)	DEPOS	328
	DO 479 I=1,NPOINT	DEPOS	329
	IF (TBL(I) .GT. XJP1-1.E-8) GO TO 480	9/12/79	1
479	CONTINUE	DEPOS	331
	PRINT 82,L,XJP1,TBL(1),TBL(NPOINT)	DEPOS	332
	GO TO 481	DEPOS	333
480	I=MINO(I,NPOINT-1)	DEPOS	334
	X1=TBL(I-1) \$ X2=TBL(I) \$ X3=TBL(I+1)	DEPOS	335
	Z1=(XJP1-X3)/(X2-X1)*(XJP1-X2)/(X3-X1)	DEPOS	336
	Z2=(XJP1-X1)/(X3-X2)*(XJP1-X3)/(X1-X2)	DEPOS	337
	Z3=(XJP1-X2)/(X3-X1)*(XJP1-X1)/(X3-X2)	DEPOS	338
	FRONT(4,L)=ECAL*EI(1)**Z1*EI(2)**Z2*EI(3)**Z3 + FRONT(4,L)	DEPOS	339
481	CONTINUE	DEPOS	340
	CALL SCATT0(TBL,EI,ECAL,NPOINT,NS,L,ESUM)	DEPOS	341
	ETOT=ESUM*RHO(M)+ETOT	DEPOS	342
483	CONTINUE	DEPOS	343
	RATIO = ECAL	DEPOS	344
	IF (IABS(NARB) .EQ. 1) RATIO = ECAL/ETOT	DEPOS	345
	DO 484 J=1,JFIN	DEPOS	346

SUBROUTINE DEPOS (Continued)

484	SS(JFINNS+J)=SS(JFINNS+J)*RATIO TOTCAL=TOTCAL+RATIO*ETOT	DEPOS 347
	C END OF NSPEC LOOP	DEPOS 348
485	CONTINUE	DEPOS 349
500	RETURN	DEPOS 350
C	*****	DEPOS 351
C	ENTRY FOR PRINTING DEPOSITION EDIT	DEPOS 352
700	WRITE (6,14)(DISCPT(I),I=1,10) JBEG=1 SUMCAL=0. DO 708 L=1,NLAYER	DEPOS 353
C**FIND IMPULSE IN EACH LAYER	ZLAGR=0. M=JMAT(L) JBNDM=JBND(L) EQE=EQSTE(M) \$ EQM=EMELT(M,1) DZLAST=0. DO 707 J=JBEG,JBNDM	DEPOS 354
	DELX(J)=X(J+1)-X(J) DZ=ZHL(J) \$ ZLAGR=(DZLAST+DZ)/2.+ZLAGR	DEPOS 355
	EPG=0. IF (J.LT. JBNDM) GO TO 701	DEPOS 356
	XRAT=(X(J)-X(J-1))/(X(J)-X(J-2))	DEPOS 357
	CPG(J)=CPG(J-1)+(CPG(J-1)-CPG(J-2))*XRAT	DEPOS 358
	PCT(J)=PCT(J-1) TC(J)=TC(J-1)+(TC(J-1)-TC(J-2))*XRAT	DEPOS 359
	P(J)=P(J-1)+(P(J-1)-P(J-2))*XRAT	DEPOS 360
	EABS(J)=EABS(J-1)+(EABS(J-1)-EABS(J-2))*XRAT	DEPOS 361
	EPGJ(J)=0. \$ DIMPMCC(J)=DIMPMCC(J-1) \$ GO TO 707	DEPOS 362
701	CONTINUE	DEPOS 363
	DO 702 NS=1,NSPEC	DEPOS 364
	JF=JFIN*(NS-1)+J	DEPOS 365
702	EPG=SS(JF)*(SSTOP(NS)-START(NS))+EPG	DEPOS 366
C	TEST FOR SETTING JSTAR	DEPOS 367
	IF (EPG*EQSTG(M).GT. 1.E7) JSTAR=J	DEPOS 368
C	STORE ENERGY (ERGS/GM), CALORIES AND SUM OF CALORIES IN -	DEPOS 369
	EPGJ(J)=EPG CPG(J)=EPG/4.186E7 SUMCAL=SUMCAL+CPG(J)*ZHL(J)/ANGLE(L) PCT(J)=100.*(1.-SUMCAL/TOTCAL) EABS(J)=SUMCAL	DEPOS 370
	TC(J)=0. \$ IF(SPH(M).GT. 0.) TC(J)=CPG(J)/SPH(M)+22.2	DEPOS 371
	IH1=H(J,1) \$ IH3=H(J,3) DH=DOLD=DHL(J) \$ EH=EHL(J)+EPG \$ EOLD=0. CALL HSTRESS	DEPOS 372
	P(J)=PHL(J)*1.E-9 H(J,1)=IH1 \$ H(J,3)=IH3 PHL(J)=SHL(J)=RHL(J)=0.	DEPOS 373
7031	IF (EQM.EQ. 0.) GO TO 707	DEPOS 374
	DIMPMCC(J)=DIMPMCC(J-1) IF (EPG.LT. EQM) GO TO 707	DEPOS 375
	IF (J.GT. JBEG.OR. J.EQ. JBNDM-1) GO TO 706	DEPOS 376
	IF (FRONT(1,L)*FRONT(4,L).EQ. 0.) GO TO 706	DEPOS 377
C	SPECIAL INTEGRATION FOR FIRST CELL OF A LAYER TO OBTAIN	DEPOS 378
C	MCLOSKEY INTEGRAL	DEPOS 379
	IF (FRONT(1,L).LT. CPG(J).OR. CPG(J).LT. FRONT(4,L)) GO TO 706	DEPOS 380
	EO=FRONT(1,L)*4.186E7 \$ EA=FRONT(4,L)*4.186E7 ENN=(EO-EA)/(EPG-EA)-1. \$ NAB=MIN1(100.,2.*EO/EA+1.)	DEPOS 381
	H1=ZLAGR+DZ/2. \$ ZL=ZLAGR-DZ/2. VOLD=ZL*(EO-EQM*(1.+ALOG(EO/EQM)))	DEPOS 382
	DZL=DZ/NAB \$ EMSUM=0.	DEPOS 383
	DO 704 I=1,NAB	DEPOS 384
	ZL=ZL+DZL \$ EHH=EA+(EO-EA)*((H1-ZL)/DZ)**ENN	DEPOS 385
	IF (EHH.LT. EQM) GO TO 705	DEPOS 386
	VNEW=ZL*(EHH-EQM*(1.+ALOG(EHH/EQM)))	DEPOS 387
	EMSUM=0.5*DZL*(VOLD+VNEW) + EMSUM	DEPOS 388
704	VOLD=VNEW	DEPOS 389
705	DIMPMCC(J)=EMSUM + DIMPMCC(J)	DEPOS 390
	GO TO 707	DEPOS 391
706	DIMPMCC(J)=DIMPMCC(J)+ZLAGR*(EPG-EQM*(1.+ALOG(EPG/EQM)))*DZ	DEPOS 392
707	DZLAST=DZ IF (NPOR(M).NE. 0) FRONT(3,L)=0. JBEG=JBNDM+1	DEPOS 393
708	CONTINUE	DEPOS 394
	COEF=1.2*SQRT(2.)	DEPOS 395

SUBROUTINE DEPOS (Continued)

DO 709 J=1,JFIN	DEPOS	422
709 DIMPMCC(J)=COEF*SQRT(DIMPMCC(J))*1.0E-3	DEPOS	423
FPCT=100.	DEPOS	424
JJ=0	DEPOS	425
FEPG=FRONT(1,1)*4.186E7	DEPOS	426
WRITE (6,15) JJ,X(1),X(1),FEPG,FRONT(1,1),FPCT,FRONT(2,1),	DEPOS	427
1 FRONT(3,1),X(1),MATL(1,1)	DEPOS	428
L=K=J1=1 \$ M=JMAT(L)	DEPOS	429
710 J2=MINO(JFIN-1,50*K,JBND(L))	DEPOS	430
DO 712 J=J1,J2	DEPOS	431
XINCH=X(J)/2.54	DEPOS	432
WRITE (6,15) J,XINCH,X(J),EPG(J),CPG(J),PCT(J),TC(J),P(J),	DEPOS	433
1 DIMPMCC(J),MATL(M,1),(H(J,1),I=1,3),J,DELX(J),EABS(J)	DEPOS	434
712 CONTINUE	DEPOS	435
IF (J2.EQ. JFIN-1) GO TO 740	DEPOS	436
J1=J2+1	DEPOS	437
IF (J2.NE. 50*K) GO TO 718	DEPOS	438
K=K+1 \$ WRITE (6,14)(DISCPT(I),I=1,10)	DEPOS	439
718 IF (J2.NE. JBND(L)) GO TO 710	DEPOS	440
WRITE (6,70) YHL(J2),CHL(J2),DHL(J2),T(J2-1),T(J2)	DEPOS	441
L=L+1 \$ M=JMAT(L)	DEPOS	442
FEPG=FRONT(1,L)*4.186E7	DEPOS	443
XINCH=X(J1)/2.54	DEPOS	444
WRITE (6,15) JJ,XINCH,X(J1),FEPG,FRONT(1,L),PCT(J2),FRONT(2,L),	DEPOS	445
1 FRONT(3,L),DIMPMCC(J2),MATL(M,1)	DEPOS	446
GO TO 710	DEPOS	447
740 WRITE(6,70) YHL(J2),CHL(J2),DHL(J2),T(J2-1),T(J2)	DEPOS	448
GO TO (742,743,744) NALPHA	DEPOS	449
742 PRINT 74,SUMCAL	DEPOS	450
GO TO 746	DEPOS	451
743 SUMCAL=3.14159*SUMCAL	DEPOS	452
PRINT 76,SUMCAL	DEPOS	453
GO TO 746	DEPOS	454
744 SUMCAL=4.18879*SUMCAL	DEPOS	455
PRINT 77,SUMCAL	DEPOS	456
746 CONTINUE	DEPOS	457
IF (IPL0T(1)+IPL0T(2)+IPL0T(3)+IPL0T(4).EQ. 0) GO TO 780	DEPOS	458
C *****	DEPOS	459
C *****	DEPOS	460
C GRAPHS OF DEPOSITED ENERGY	DEPOS	461
JEND=JFIN-1 \$ L=1 \$ JJ=1\$ XPL(1)=X(1)	DEPOS	462
DO 754 J=1,JEND	DEPOS	463
JJ=JJ+1	DEPOS	464
IF (J.EQ. JBND(L)) GO TO 752	DEPOS	465
XPL(JJ)=0.5*(X(J)+X(J+1))	DEPOS	466
GO TO 754	DEPOS	467
752 XPL(JJ)=X(J)	DEPOS	468
IF (J.EQ. JEND) GO TO 754	DEPOS	469
JJ=JJ+1 \$ XPL(JJ)=X(J)	DEPOS	470
ITITLE(9)=10HDEPTH - CM	DEPOS	471
DO 753 NN=10,24	DEPOS	472
753 ITITLE(NN)=10H	DEPOS	473
L=L+1	DEPOS	474
754 CONTINUE	DEPOS	475
JMAX=JJ	DEPOS	476
DO 776 I=1,4	DEPOS	477
IF (IPL0T(I).EQ. 0) GO TO 776	DEPOS	478
GO TO (756,758,760)I	DEPOS	479
756 ITITLE(17)=10HABSORBED E \$ ITITLE(18)=10HNERGY - CA	DEPOS	480
ITITLE(19)=10HL/G \$ GO TO 762	DEPOS	481
758 ITITLE(17)=10HTEMP. FROM \$ ITITLE(18)=10H ABS. ENER	DEPOS	482
ITITLE(19)=10HGY - DEG C	DEPOS	483
GO TO 762	DEPOS	484
760 ITITLE(17)=10HPSEUDO PRE \$ ITITLE(18)=10HSSURE AT D	DEPOS	485
ITITLE(19)=10HEP. - KBAR	DEPOS	486
762 CONTINUE	DEPOS	487
L=1 \$ JJ=1 \$ YPL(1)=FRONT(1,1)	DEPOS	488
DO 774 J=1,JEND	DEPOS	489
JJ=JJ+1	DEPOS	490
GO TO (769,770,771) I	DEPOS	491
769 YPL(JJ)=CPG(J) \$ GO TO 772	DEPOS	492
770 YPL(JJ)= TC(J) \$ GO TO 772	DEPOS	493
771 YPL(JJ)= P(J) \$ GO TO 772	DEPOS	494
772 IF (J.LT. JBND(L)) GO TO 774	DEPOS	495
IF (J.EQ. JEND) GO TO 774	DEPOS	496
JJ=JJ+1 \$ L=L+1	DEPOS	

SUBROUTINE DEPOS (Concluded)

774	YPL(JJ)=FRONT(I,L)	DEPOS	497
	CONTINUE	DEPOS	498
	CALL GRAPH4(XPL,YPL,JMAX,1,XMAX(I),XMIN(I),YMAX(I),YMIN(I),ITITLE,	DEPOS	499
	1 I A)	DEPOS	500
776	CONTINUE	DEPOS	501
780	RETURN	DEPOS	502
	END	DEPOS	503

SUBROUTINE DFRAC2

	SUBROUTINE DFRAC2(SXX, SYY, STT, TXY, EXX1, EYY1, ETT1, EXY1, P, NM, NT, DH0,	DFRACT2	2
1	DOLD0, DT0, EOLD, EH, EQSTCM, EQSTGM, ELMU, RH0S, TSR, Y, YD, F, M, J, K, ALFA)	DFRACT2	3
C		DFRACT2	4
C	PJ ESTIMATE OF PRESSURE	DFRACT2	5
C	PA COMPUTED PRESSURE BASED ON PJ	DFRACT2	6
C	PN, PG PRESSURES ASSOCIATED WITH NUCLEATION AND GROWTH	DFRACT2	7
C	NM RELATIVE VOID VOLUME	DFRACT2	8
C	NT VOID DENSITY, NUMBER/CM3	DFRACT2	9
C	TSR(1) GROWTH CONSTANT = 3/(4*ETA)	DFRACT2	10
C	TSR(2) GROWTH THRESHOLD, DYN/CM2	DFRACT2	11
C	TSR(3) NUCLEATION RADIUS PARAMETER, CM	DFRACT2	12
C	TSR(4), PARAMETERS IN THE NUCLEATION FUNCTION :	DFRACT2	13
C	TSR(6) NDOT = T4*EXP((P-TSR(5))/TSR(6))	DFRACT2	14
C	TSR(5) NUCLEATION THRESHOLD, DYN/CM2	DFRACT2	15
C	VV0, VVA VOID VOLUME, CM3/G	DFRACT2	16
C	VGA VOID VOLUME ASSOCIATED WITH GROWTH, CM3/G	DFRACT2	17
C	VNA VOID VOLUME ASSOCIATED WITH NUCLEATION, CM3/G	DFRACT2	18
C		DFRACT2	19
	DIMENSION TSR(6,30)	DFRACT2	20
	REAL NM,NT	DFRACT2	21
	DATA SMF/1.88/	DFRACT2	22
	IF (NM .LT. 0.) RETURN	DFRACT2	23
	NTRY=0	DFRACT2	24
	DOLD=DOLD0	DFRACT2	25
	VVG=NM/DOLD	DFRACT2	26
	VVA=VV0	DFRACT2	27
	VSG=1./DOLD-VVG	DFRACT2	28
	PSG=P/(VSG*DOLD)	DFRACT2	29
	DVG=1./DH0-1./DOLD	DFRACT2	30
	IF (ABS(DVG) .LT. 1.E-9) DVG=1.E-9	DFRACT2	31
	DV=DVG	DFRACT2	32
	IF (TSR(M,7) .EQ. 0.) TSR(M,7)=8.*3.1416*TSR(M,3)**3*TSR(M,4)	DFRACT2	33
C	*****	DFRACT2	34
C	BEGIN SUBCYCLING LOOP FOR CASE OF LARGE STRAIN	DFRACT2	35
C	*****	DFRACT2	36
	NLOOP=MAX1(1., -2.*DV*EQSTCM/VSG/TSR(M,5)+0.5, 2.5*TSR(M,1)*DT0*	DFRACT2	37
1	AMIN1(P-TSR(M,2), TSR(M,2)))	DFRACT2	38
100	DELV=DV/NLOOP	DFRACT2	39
	EXX=EXX1*DELV/DVG	DFRACT2	40
	EYY=EYY1*DELV/DVG	DFRACT2	41
	ETT=ETT1*DELV/DVG	DFRACT2	42
	EXY=EXY1*DELV/DVG	DFRACT2	43
	VH=1./DOLD	DFRACT2	44
	YT=Y	DFRACT2	45
	DT=DELV/DVG*DT0	DFRACT2	46
	A1=TSR(M,1)*DT	DFRACT2	47
	DPJ=0.2*(ABS(TSR(M,5))+ABS(P))	DFRACT2	48
	D0 380 NL=1, NLOOP	DFRACT2	49
	VH=VH+DELV	DFRACT2	50
	DH=1./VH	DFRACT2	51
	DE=(EH-EOLD)*(VH-1./DOLD)/DVG	DFRACT2	52
	E=(EH-EOLD)*(VH-1./DOLD0)/DVG+EOLD	DFRACT2	53
	TEMP1=1.-RH0S*EQSTGM*E/EQSTCM	DFRACT2	54
C		DFRACT2	55
C	ESTIMATE OF PRESSURE BASED ON STRAIN, GROWTH, NUCLEATION	DFRACT2	56
	PN=0.	DFRACT2	57
	YS=VSG**2*RH0S/EQSTCM	DFRACT2	58
	YSC=YS*(PSG+RH0S*EQSTGM*DE)	DFRACT2	59
	DVS=DELV	DFRACT2	60
	PG=AMAX1((YSC-DELV)/YS, EQSTCM*(1./RH0S/(VSG+DELV)-TEMP1))	DFRACT2	61
	PS=PG	DFRACT2	62
	PJ=F3	DFRACT2	63
	IF (C.5*(PJ+PSG) .GT. AMAX1(TSR(M,2), TSR(M,5))) GO TO 300	DFRACT2	64
	IF (DELV .GT. 0.) PN=2.*TSR(M,6)*ALOG(DELV*DH/TSR(M,7)/DT)+	DFRACT2	65
1	2.*TSR(M,5) - PSG	DFRACT2	66
	IF (VV0 .LE. 0.) GO TO 150	DFRACT2	67
	XN=0. \$ XP=1.0	DFRACT2	68
	IF (PSG .LT. TSR(M,5)) XN=TSR(M,7)/DH*DT*EXP((PSG-TSR(M,5))/TSR	DFRACT2	69
1	(M,6))	DFRACT2	70
	IF (PSG .LT. TSR(M,2)) XP=EXP(A1*(PSG-TSR(M,2)))	DFRACT2	71
	YG=VV0*XP*A1/2.	DFRACT2	72
	YGC= VVG*(XP-1.)-YG*PSG	DFRACT2	73
	YN=XN/(2.*TSR(M,6))	DFRACT2	74
	YNC=XN-YN*PSG	DFRACT2	75
	PG=(DELV-YSC-YGC-YN)/(-YS+YG+YN)	DFRACT2	76

SUBROUTINE DFRAC (Continued)

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CH=1.
IF (0.5*(PG+PS0).GT. TSR(M,2))YG=YGC=CH=0.
IF (0.5*(PG+PS0).GT. TSR(M,5))YN=YNC=CH=0.
IF (CH.EQ.0.)PG=(DELV-YSC-YGC-YN)/(-YS+YG+YN)
IF (DELV.GT.0. .AND. PS0 .LT. TSR(M,2))PG=AMIN1(PG,TSR(M,2))
PJ=AMAX1(PS,PG,PN)
150 DVS=1./RH0S/(PJ/EQSTCM+TEMP1)-VS0
VVA=VV0+DELV-DVS
NC=0.
C *****
C BEGIN ITERATION LOOP
C *****
200 NC=NC+1
VV=VV0+DELV-DVS
PJ=PA=EQSTCM*(1./RH0S/(VS0+DVS)-TEMP1)
PN=AMIN1(0.5*(PA+PS0)-TSR(M,5),0.)
IF (PN .LT. 0.) PN=EXP(PN/TSR(M,6))
VNA=TSR(M,7)*PN*DT/DH
VGA=VV0
PG=AMIN1(0.5*(PA+PS0)-TSR(M,2),0.)
IF (PG .LT. 0.) VGA=VV0*EXP(A1*PG)
VVA=VGA+VNA
DVSA=1./RH0S/(PJ/EQSTCM+TEMP1)-VS0
DELVA=DVSA+VVA-VV0
C TEST FOR COMPLETION OF ITERATIONS
IF (ABS(DELVA-DELV)/VS0 .LT. 2.E-5 .AND. ABS(DVS-DVSA)/VS0 .LT.
1 1.E-5) GO TO 300
IF (NC.LT.30) GO TO 250
IF (NTRY.LT.5)GO TO 450
PRINT 1250,J,K,M,PJ,DELV,DELVA,DELVB,DELVC
GO TO 300
C DELVA IS RECENT VALUE, DELVB IS LARGER STORED VALUE, AND
C DELVC IS SMALLER STORED VALUE.
250 IF (NC.EQ.1) GO TO 270
IF (NC .EQ. 2) GO TO 260
IF (DELVC .GT. DELV) GO TO 265
IF (DELVB .LT. DELV) GO TO 260
IF (DELVA .GT. DELV) GO TO 265
260 DVS=DVSA+(DVSB-DVSA)/(DELVB-DELVA)*(DELV-DELVA)
IF (MOD(NC+2,3).EQ.0) DVS=.5*(DVSA+DVSB)
GO TO 275
265 DVS=DVSA+(DVSC-DVSA)/(DELVC-DELVA)*(DELV-DELVA)
IF (MOD(NC+2,3).EQ.0) DVS=.5*(DVSA+DVSC)
GO TO 275
270 PJ=PA+(DELV-DELVA)/(VGA*A1/2.-YS +VNA/2./TSR(M,6))
PN=PJ
IF (VNA+DELV-DELVA .GT. 0. .AND. VNA .GT. 0.) PN=2.*TSR(M,6)*
1 ALOG((VNA+DELV-DELVA)/VNA) + PA
PJ=AMAX1(PJ,0.5*(PN+PJ))
PJ=PA+SIGN(AMIN1(ABS(PJ-PA),DPJ),DELVA-DELV)
DVS=VS0*(1./(1.+(PJ*YS-YSC)/VS0)-1.)
275 IF (NC-2) 290,285,280
280 IF ((DELVB.GT.DELV.AND.DELVA.GT.DELVB).OR.
C (DELVA.LT.DELVC.AND.DELVC.LT.DELV)) GO TO 200
IF (DELVC.GT.DELV.OR.(DELVB.GT.DELV.AND.DELVA.GT.DELV))
C GO TO 290
285 DELVC = DELVA
DVSC = DVSA
GO TO 292
290 DELVB = DELVA
DVSB = DVSA
IF (NC.EQ.1) GO TO 200
292 IF (DELVB.GT.DELVC) GO TO 200
DELVA = DELVB
DVSA = DVSB
DELVB = DELVC
DVSB = DVSC
DELVC = DELVA
DVSC = DVSA
GO TO 200
C ENDING ROUTINE
C
300 NM=VVA*DH
NT=NT*DH/D0LD+TSR(M,4)*PN*DT
IF (NM .GT. 0.6) GO TO 400
DFRACT2 77
DFRACT2 78
DFRACT2 79
DFRACT2 80
DFRACT2 81
10/8/79 34
DFRACT2 83
DFRACT2 84
DFRACT2 85
DFRACT2 86
DFRACT2 87
DFRACT2 88
DFRACT2 89
DFRACT2 90
DFRACT2 91
10/8/79 35
DFRACT2 94
DFRACT2 95
DFRACT2 96
10/8/79 36
DFRACT2 98
DFRACT2 99
DFRACT2 100
DFRACT2 101
DFRACT2 103
DFRACT2 104
DFRACT2 105
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DFRACT2 115
DFRACT2 116
DFRACT2 117
DFRACT2 118
10/8/79 37
DFRACT2 120
DFRACT2 121
10/8/79 38
DFRACT2 123
DFRACT2 124
DFRACT2 125
DFRACT2 126
DFRACT2 127
DFRACT2 128
DFRACT2 129
10/8/79 39
10/8/79 40
10/8/79 41
10/8/79 42
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10/8/79 49
10/8/79 50
10/8/79 51
10/8/79 52
10/8/79 53
10/8/79 54
10/8/79 55
10/8/79 56
DFRACT2 147
DFRACT2 148
DFRACT2 149
DFRACT2 150
DFRACT2 151
DFRACT2 152

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SUBROUTINE DFRACT (Concluded)

BETA=2.*TXY*ALFA/NL00P	DFRACT2	153
ELMUF=2.*ELMU*AMAX1(1.-SMF*VVA*DH,0.)	DFRACT2	154
WS1=0.6667*(D0LD-DH)/(D0LD+DH)	DFRACT2	155
TXY=TXY+ELMUF*EXY+(SYY-SXX)*ALFA/NL00P	10/8/79	57
SXX=SXX+ELMUF*(EXX-WS1)+BETA	DFRACT2	157
SYY=SYY+ELMUF*(EYY-WS1)-BETA	DFRACT2	158
STT=STT+ELMUF*(ETT-WS1)	DFRACT2	159
WS4=SXX**2+SYY**2+STT**2+2.*TXY**2	DFRACT2	160
YE=Y*F*AMAX1(1.-4.*VVA*DH,0.)	DFRACT2	161
IF (WS4 .LT. YE**2/1.5) GO TO 340	DFRACT2	162
WS3=YE/SQRT(1.5*WS4)	DFRACT2	163
PTERM=(D0LD-DH)/(D0LD+DH)/DT/TSR(M,1)	DFRACT2	164
WS5=1.5/TSR(M,1)/DT	DFRACT2	165
SXX=SXX*WS3+EXX*WS5-PTERM	DFRACT2	166
SYY=SYY*WS3+EYY*WS5-PTERM	DFRACT2	167
STT=STT*WS3+ETT*WS5-PTERM	DFRACT2	168
TXY=TXY*WS3+EXY*WS5	10/8/79	58
340 CONTINUE	DFRACT2	170
PS0=PJ	DFRACT2	171
P=PJ*(VS0+DVS)*DH	DFRACT2	172
Y=YT	DFRACT2	173
VV0=VVA	DFRACT2	174
VS0=VH-VVA	DFRACT2	175
380 D0LD=DH	DFRACT2	176
RETURN	DFRACT2	177
C	DFRACT2	178
C END WITH SEPARATION	DFRACT2	179
400 P=0.	DFRACT2	180
Y=0.	DFRACT2	181
SXX=0.	DFRACT2	182
SYY=0.	DFRACT2	183
STT=0.	DFRACT2	184
TXY=0.	DFRACT2	185
NM=-ABS(NM)	DFRACT2	186
RETURN	DFRACT2	187
C	DFRACT2	188
C PROVISION FOR ABORT IN CASE OF ITERATION FAILURE	DFRACT2	189
450 NTRY=NTRY+1	DFRACT2	190
DV=1./DH0-1./D0LD	DFRACT2	191
NL00P=MAX1(3.,-4.*2.**NTRY*DVEQSTCM/VS0/TSR(M,5)+0.5)	DFRACT2	192
GO TO 100	DFRACT2	193
C FORMATS	DFRACT2	194
1250 FORMAT (30H ITERATION FAILURE IN DFRACT/5H J,K=212,3H M=12,	DFRACT2	195
1 4H PJ=1PE10.3,6H DELV=E10.3,7H DELVA=E10.3,7H DELVB=E10.3,	DFRACT2	196
2 7H DELVC=E10.3)	DFRACT2	197
END	DFRACT2	198

SUBROUTINE EDIT

C	SUBROUTINE EDIT	EDIT	2
C	* EDIT LISTS COORINATE QUANTITIES FOR TIME OF TEOIT	EDIT	3
C	INPUT - JSTAR.	EDIT	4
C	OUTPUT - NTEX.	EDIT	5
C		EDIT	6
C	INTEGER H,POROUS,PRESS,RINTER,SOLID,SPALL	EDIT	7
	REAL MATL,NEM,NET,NEMH,NETH	PUFCOM	2
C	MISCELLANEOUS	PUFCOM	3
	COMMON AZERO(1),CEF,CKS,OAVG,OELTIM,DISCPT(10),DOLO,ORHO,OTMAX,	PUFCOM	4
	1 DTMIN,OTN,OTNH,DU,OX,EOLD,F,FAC,FIRST,J,JCYCS,JINIT,	PUFCOM	5
	2 JFIN,JREZON(15),JSMAX,JSTAR,JTS,LSUR(30),M,MAXPR(30),N,NCYCS,	PUFCOM	6
	3 NEDIT,NPERN,NR,NREZON,NSCRB(6),NSEPRAT,NSPALL,NTEDT,	PUFCOM	7
	4 NTEX,NTR(15),POLD,P6(20),R(30),RLAST,SLAST,SMAX,TEOIT(50),	PUFCOM	8
	5 TF,TIME,TJ,TREZON,TS,T6(20),ULAST,UOLD,UZERO,XLAST,XNOW,XOLD	PUFCOM	9
	1 ,XJDOIT(20)	PUFCOM	10
C	HALFSTEP VALUES	PUFCOM	11
	COMMON DH,OHLAST,DUH,EH,PH,RH,RHLAST,SH,SHLAST,UH,UHLAST,XH,XHLAST	PUFCOM	12
	1 ,NEMH,NETH	PUFCOM	13
C	CONOITION INOICATORS	PUFCOM	14
	COMMON INF,LINTER,MIRROR,NORMAL,POROUS,PRESS,RINTER,SOLIO,SPALL	PUFCOM	15
C	CELL LAYOUT	PUFCOM	16
	COMMON DX(30),JBND(30),JMAT(30),NAUTO,MATL(6,2),NLAYER,NMTRLS,	PUFCOM	17
	1 THK(30)	PUFCOM	18
C	COORDINATE ARRAYS	PUFCOM	19
	COMMON/COORD/X(200),X0(200),CHL(200),DHL(200),DPDD(200),DPDE(200),	COORDC02	
	1 EHL(200),H(200,3),NEM(200),NET(200),PHL(200),RHL(200),SDT(200),	COORDC03	
	2 SHL(200),T(200),U(200),YHL(200),ZHL(200)	COORDC04	
	COMMON /IND/ IEOS(6),INDK(20),NALPHA,NCMP(6),NFR(6),NPOR(6),	COORDC05	
	1 NDS(6),NPR(6),NCON(6),NVAR(6)	INDCOM	2
	COMMON /PES/ LVMAX,LVTOT,LVAR(200),COM(4000)	INDCOM	3
	DIMENSION P1(300),P2(300),EMOM(300)	EDIT	11
C		EDIT	12
C		EDIT	13
C		EDIT	14
C		EDIT	15
C	PRINTOUT FOR EACH EOIT	EDIT	16
	NTEX=NTEX+1	EDIT	17
	CALL SECOND(CHANGE) \$ OUR=CHANGE-FIRST	EDIT	18
	JSTARD=MIN0(JSTAR+1,JFIN-1) \$ NPTS=JSTARD-JINIT+1	EDIT	19
	WRITE (6,1025) (DISCPT(I),I=1,10)	EDIT	20
	WRITE(6,1026) NTEX,N,TIME,JSTAR,DUR,DTNH	EDIT	21
	EMSUM = EMOM(JINIT) = 0.	EDIT	22
	J1=JINIT \$ L=1 \$ M=JMAT(L)	EDIT	23
4	J2=MIN0(JSTARD,JBND(L))	EDIT	24
	NJ=J2-J1+1	EDIT	25
	IF (NPR(M) .EQ. 1) GO TO 7	EDIT	26
	IF (NFR(M) .EQ. 1 .OR. NFR(M) .EQ. 2) GO TO 7	EDIT	27
	IF (NFR(M) .EQ. 3) GO TO 5	EDIT	28
	IF (NPOR(M) .EQ. 3) GO TO 10	EDIT	29
	IF (NDS(M) .EQ. 0 .OR. NDS(M) .EQ. 1 .OR. NDS(M) .EQ. 4) GO TO 5	EDIT	30
	IF (NPOR(M) .EQ. 4) GO TO 9	EDIT	31
	GO TO 7	EDIT	32
5	DO 6 J=J1,J2	EDIT	33
	P1(J)=YHL(J)	EDIT	34
6	P2(J)=SHL(J)-PHL(J)	EDIT	35
	IF (NFR(M) .GE. 3) GO TO 10	EDIT	36
	N1 = 10H YIELD \$ N2 = 10H DEVIATOR	EDIT	37
	GO TO 13	EDIT	38
7	DO 8 J=J1,J2	EDIT	39
	P1(J)=NEM(J)	EDIT	40
8	P2(J)=NET(J)	EDIT	41
	N1 = 10H NEM \$ N2 = 10H NET	EDIT	42
	IF (NPR(M) .EQ. 1) N1 = 10H FBURN	EDIT	43
	IF (NFR(M) .NE. 0) N1=10H RVV	EDIT	44
	GO TO 13	EDIT	45
9	N1=10H EVP \$ N2=10H DEVIATOR	EDIT	46
	DO 91 J=J1,J2	EDIT	47

SUBROUTINE EDIT (Concluded)

	P1(J)=NEM(J)	EOIT	48
91	P2(J)=SHL(J)-PHL(J)	EDIT	49
	GO TO 13	EDIT	50
10	00 11 J=J1,J2	EDIT	51
	IF (H(J,3)-2) 101,11,102	EDIT	52
101	P1(J)=NEM(J)	EDIT	53
	P2(J)=NET(J)	EDIT	54
	GO TO 11	EOIT	55
102	LV=LVAR(J)	EOIT	56
	IF (NPOR(M) .EQ. 3 .AND. H(J,3) .EQ. 5R M) LV=LVAR(J)+3	EOIT	57
	P1(J)=COM(LV)	EDIT	58
	P2(J)=COM(LV+1)	EDIT	59
11	CONTINUE	EOIT	60
	N1=10H Y/NEM/RVV	EDIT	61
	N2=10HSD/NET/ENV	EDIT	62
13	CONTINUE	EOIT	63
	DO 14 J=J1,J2	EDIT	64
14	EMOM(J+1)=EMSUM=0.5*ZHL(J)*(U(J)+U(J+1))+EMSUM	EDIT	65
	WRITE (6,1029) N1,N2	EDIT	66
	IF (DHL(J2) .GT. 1.) WRITE (6,1028) (J,X(J),U(J),RHL(J),PHL(J),SHL(J),	EOIT	67
	1,EHL(J),DHL(J),CHL(J),(H(J,I),I=1,3),MATL(M,1),EMOM(J),P1(J),P2(J)	EDIT	68
	2,J=J1,J2)	EOIT	69
	IF (DHL(J2) .LE. 1.) WRITE (6,1027) (J,X(J),U(J),RHL(J),PHL(J),SHL(J),	EDIT	70
	1,FHL(J),DHL(J),CHL(J),(H(J,I),I=1,3),MATL(M,1),EMOM(J),P1(J),P2(J)	EDIT	71
	2,J=J1,J2)	EDIT	72
	IF (J2 .EQ. JSTARO) GO TO 20	EDIT	73
	J1=J2+1	EDIT	74
	L = L+1 \$ M = JMAT(L) \$ GO TO 4	EDIT	75
20	CONTINUE	EDIT	76
	RETURN	EDIT	77
1025	FORMAT (1H0,10A10)	EOIT	78
1026	FORMAT(18H0 TIME EDIT NO.13,7H AT N =15,8H, TIME =1PE12.5,	EDIT	79
	1 14H SECS, JSTAR =15,14H, CALC TIME IS 0PF10.3,13H SECS, DTNH =	EDIT	80
	2 1PE10.3,5H SECS/)	EDIT	81
1027	FORMAT(15,0PF9.6,F9.0,1P4E10.3,0PF8.6,1PE11.4,3R2,1X,A9,1PE10.3,	EOIT	82
	1 1P2E11.3)	EDIT	83
1028	FORMAT(15,0PF9.6,F9.0,1P4E10.3,0PF8.4,1PE11.4,3R2,1X,A9,1PE10.3,	EDIT	84
	1 1P2E11.3)	EDIT	85
1029	FORMAT (4X,1HJ,8X,1HX,8X,1HU,7X,3HRHL,7X,3HPHL,7X,3HSHL,7X,3HEHL,	EOIT	86
	1 5X,3HDHL,8X,3HCHL,2X,4HCOND,17X,3HMOM,1X,A10,1X,A10/	EDIT	87
	2 5H CELL,7X,2HCM,3X,6HCM/SEC,3(10H OYN/CM2),6X,4HERGS,2X,	EDIT	88
	3 6HGM/CM3,5X,6HCM/SEC,22X,4HTAPS)	EOIT	89
	ENO	EDIT	90

SUBROUTINE EOSTAB

	SUBROUTINE EOSTAB(NCALL,IN,XN,YN,ZN)	EOSTAB	2
	DIMENSION X(30),Z(30),EX(30)	EOSTAB	3
	IF (NCALL .GT. 0) GO TO 100	EOSTAB	4
C		EOSTAB	5
C	INITIALIZE AND READ DATA	EOSTAB	6
C		EOSTAB	7
	READ (IN,1001) A1,IMAX,12,13	10/8/79	1
	IF (12 .NE. 10H VOLUME) 12=10H DENSITY	EOSTAB	9
	IF (13 .NE. 10H LOG) 13=10H LINEAR	EOSTAB	10
	PRINT 1001,A1,IMAX,12,13	EOSTAB	11
	PRINT 1003,IN	EOSTAB	12
	READ (IN,1002) A1,(X(1),Z(1), I=1,IMAX)	EOSTAB	13
	PRINT 1012,A1,(X(1),Z(1), I=1,IMAX)	EOSTAB	14
C	VOLUME TRANSFORMATION	EOSTAB	15
	IF (12 .NE. 10H VOLUME) GO TO 45	EOSTAB	16
	DO 30 I=1,IMAX	EOSTAB	17
30	X(I)=1./X(I)	EOSTAB	18
45	IM1=IMAX-1	EOSTAB	19
	DO 50 I=1,IM1	EOSTAB	20
50	EX(I)=(Z(I+1)-Z(I))/(X(I+1)-X(I))	EOSTAB	21
	IF (13 .NE. 10H LOG) GO TO 80	EOSTAB	22
	DO 65 I=1,IM1	EOSTAB	23
	IF (Z(I) .LE. 0. .OR. Z(I+1) .LE. 0.) GO TO 65	EOSTAB	24
	EX(I)=ALOG(Z(I+1)/Z(I))/ALOG(X(I+1)/X(I))	EOSTAB	25
65	CONTINUE	EOSTAB	26
80	IM2=IMAX-2	EOSTAB	27
	N1=2	EOSTAB	28
	NM=IMAX-1	EOSTAB	29
	NORDER=1	EOSTAB	30
	IF (X(1) .LT. X(2)) RETURN	EOSTAB	31
	NORDER=0	EOSTAB	32
	N1=IMAX-1	EOSTAB	33
	NM=2	EOSTAB	34
	IM2=IMAX-1	10/8/79	2
	RETURN	EOSTAB	35
C		EOSTAB	36
C	CALCULATE PRESSURE	EOSTAB	37
100	IT=N1-NORDER	EOSTAB	38
	IF (XN .LT. X(N1)) GO TO 175	EOSTAB	39
	IT=NM-1+NORDER	EOSTAB	40
	IF (XN .GT. X(NM)) GO TO 175	EOSTAB	41
	DO 140 I=2,IM2	EOSTAB	42
	N4=I+1	EOSTAB	43
	IF (NORDER .EQ. 0) N4=IMAX-I+1	10/8/79	3
	IT=N4-NORDER	EOSTAB	45
	IF (XN .LT. X(N4)) GO TO 175	EOSTAB	46
140	CONTINUE	EOSTAB	47
175	IF (13 .EQ. 10H LOG) GO TO 190	EOSTAB	48
180	ZN=Z(IT)+(XN-X(IT))*EX(IT)	EOSTAB	49
	RETURN	EOSTAB	50
190	IF (Z(IT) .LE. 0. .OR. Z(IT+1) .LE. 0.) GO TO 180	EOSTAB	51
	ZN=Z(IT)*(XN/X(IT))*EX(IT)	EOSTAB	52
	RETURN	EOSTAB	53
1001	FORMAT(A10,I10,2A10)	EOSTAB	54
1002	FORMAT(A10,6E10.3/(10X,6E10.3))	EOSTAB	55
1003	FORMAT(1H+,79X,4H IN=,12,11H EOSTAB P-V)	EOSTAB	56
1012	FORMAT(A10,1P6E10.3/(10X,6E10.3))	EOSTAB	57
	END	EOSTAB	58

SUBROUTINE EQST

	SUBROUTINE EQST(EJ,DJ,PJ,MJ,CJ,DPDDJ,DPDEJ)	EQST 2
C		EQST 3
C	COMPUTES PRESSURE AND SOUND SPEED FOR SOLIDS AND EXPLOSIVES	EQST 4
C	* MIE-GRUNEISEN FOR COMPRESSION	EQST 5
C	PUFF HUGONIOT IN P - MU FORM	EQST 6
C	MURNAGHAN HUGONIOT FORM (FOR EQSTS=1.0)	EQST 7
C	LINEAR US-UP HUGONIOT FORM (FOR EQSTS=2.0)	EQST 8
C	* EXPANSION EQUATION OF STATE FOR DENSITIES LESS THAN RHOS	EQST 9
C	* POLYTROPIC GAS EQUATION FOR EXPLOSIVES (NPR=1)	EQST 10
C	INPUT - FORMAL PARAMETERS EJ, DJ, MJ, CJ.	EQST 11
C	OUTPUT - PJ, CJ.	EQST 12
C		EQST 13
C	NAMED COMMON	EQSTCOM2
	REAL MU,MUM	EQSTCOM3
	COMMON /EQS/ EQSTA(6),EQSTC(6),EQSTD(6),EQSTE(6),EQSTG(6),	EQSTCOM4
1	EQSTH(6),EQSTN(6),EQSTS(6),EQSTV(6),CZQ(6),CWQ(6),C2(6)	EQSTCOM5
	COMMON /MELT/ EMELT(6,5),SPH(6),THERM(6,8)	EQSTCOM6
	COMMON /RHO/ RHO(6),RHOS(6)	EQSTCOM7
	COMMON /TSR/ TSR(6,30),EXMAT(6,20),TENS(6,3)	EQSTCOM8
	COMMON /Y/ Y0(6),YADD(6),MU(6),MUM,YADDM	EQSTCOM9
	COMMON /IND/ IEOS(6),INDK(20),NALPHA,NCMP(6),NFR(6),NPOR(6),	INDCOM 2
1	NDS(6),NPR(6),NCON(6),NVAR(6)	INDCOM 3
	DIMENSION NHUG(6),AMURN(6),BPMURN(6),S1(6)	EQST 16
C		EQST 17
C	EXPLANATION OF SOME MODIFIED PUFF EXPANSION MODEL PARAMETERS	EQST 18
C		EQST 19
C	* ABSOLUTE VALUE OF EQSTV IS EXPONENT IN GRUNEISEN EXPRESSION,	EQST 20
C --	DEFAULT VALUE OF EXPONENT FOR EQSTV=0. IS 0.5	EQST 21
C	* IF EQSTV .GT. 0., THEN MCCLOSKEY-THOMPSON LOG VARIATION IS	EQST 22
C --	USED FOR EJ .GT. SUBL ENERGY	EQST 23
C	* EQSTA IS THE COEFFICIENT OF THE SECOND TERM ASSUMED IN THE	EQST 24
C --	GRUNEISEN SERIES AND A NONZERO VALUE INDICATES THAT THE	EQST 25
C --	PRESSURE-DENSITY SLOPES OF MIE-GRUNEISEN EOS AND EXPANSION	EQST 26
C --	EOS HAVE BEEN MATCHED AT THE INITIAL SOLID DENSITY.	EQST 27
C --	IF EQSTA=0. OR IS UNSPECIFIED, THEN THE PRESSURE-VOLUME	EQST 28
C	SLOPE IS NOT MATCHED.	EQST 29
C		EQST 30
C		EQST 31
C	**** INITIALIZATION PORTION	*****EQST 32
C		EQST 33
	IF (EQSTN(MJ) .GT. 0.) GO TO 200	EQST 34
	EQSTN(MJ) = 1.	EQST 35
	IF (EQSTG(MJ)*EQSTE(MJ)*RHOS(MJ) .NE. 0.) EQSTN(MJ) = EQSTC(MJ)/	EQST 36
1	(EQSTG(MJ)*EQSTE(MJ)*RHOS(MJ))	EQST 37
	IF (EQSTV(MJ) .GT. 0.) PRINT 1005	EQST 38
	ENN=ABS(EQSTV(MJ))	EQST 39
	IF (EQSTV(MJ) .NE. 0.) PRINT 1007,ENN	EQST 40
	AMURN(MJ)=0.	EQST 41
	IF (EQSTA(MJ) .EQ. 0.) GO TO 35	EQST 42
	PRINT 1009,EQSTA(MJ)	EQST 43
	AMURN(MJ)=(EQSTA(MJ)+ENN*(EQSTH(MJ)-EQSTG(MJ)))/EQSTG(MJ)	EQST 44
	IF (AMURN(MJ)+EQSTN(MJ) .GT. 0.) GO TO 30	EQST 45
	PRINT 1055,EQSTN(MJ),AMURN(MJ)	EQST 46
	STOP	EQST 47
30	EQSTA(MJ)=AMURN(MJ)	EQST 48
35	CONTINUE	EQST 49
	NHUG(MJ) = 1	EQST 50
	IF (EQSTS(MJ) .EQ. 1.) NHUG(MJ) = 2	EQST 51
	IF (EQSTS(MJ) .EQ. 2.) NHUG(MJ) = 3	EQST 52
	NHUGM = NHUG(MJ)	EQST 53
	GO TO (180,40,60) NHUGM	EQST 54
C	INITIALIZE FOR MURNAGHAN HUGONIOT FORM	EQST 55
C	P = A*((D/RHOS)**B0P-1.)	EQST 56
C	-A=-B0/B0P IS READ AS -C-. -B0P- IS READ IN AS -D-	EQST 57
40	AMURN(MJ) = EQSTC(MJ)	EQST 58
	BPMURN(MJ) = EQSTD(MJ)	EQST 59
	EQSTC(MJ) = EQSTC(MJ)*EQSTD(MJ)	EQST 60
	EQSTD(MJ) = 0.5*EQSTC(MJ)*(EQSTD(MJ)-1.)	EQST 61

SUBROUTINE EQST (Continued)

PRINT 1010,EQSTC(MJ),EQSTD(MJ)	EQST 62
GO TO 180	EQST 63
C INITIALIZE LINEAR US-UP HUGONIOT FORM	EQST 64
C US = C1 + S1 * UP	EQST 65
C -C1- IS READ IN AS -C-. -S1- IS READ IN AS -D-	EQST 66
60 S1(MJ) = EQSTD(MJ)	EQST 67
EQSTC(MJ) = RHOS(MJ)*EQSTC(MJ)**2	EQST 68
EQSTD(MJ) = EQSTC(MJ)*(2.*EQSTD(MJ)-1.)	EQST 69
PRINT 1020,EQSTC(MJ),EQSTD(MJ)	EQST 70
GO TO 180	EQST 71
180 IF (EQSTN(MJ) .EQ. 1.) PRINT 1050	EQST 72
RETURN	EQST 73
C	EQST 74
C **** COMPUTATION PORTION	****EQST 75
C	EQST 76
200 IF (NPR(MJ) .EQ. 1) GO TO 400	EQST 77
AMU=1.333*MUM \$ IF (EJ .GT. EMELT(MJ,1)) AMU=0.	EQST 78
VJ=RHOS(MJ)/DJ \$ EMU=(1.-VJ)/VJ	EQST 79
IF (EMU .GE. 0.) GO TO 300	EQST 80
C EQST FOR EXPANDED ZONES	EQST 81
ENN=0.5 \$ ESUBC=1.0 \$ IF (EQSTV(MJ) .NE. 0.) ENN=ABS(EQSTV(MJ))	EQST 82
IF (EQSTV(MJ) .GT. 0. .AND. EJ .GT. EQSTE(MJ)) ESUBC=1.+ALOG(EJ/	EQST 83
1 EQSTE(MJ))	EQST 84
ERAT=EJ/EQSTE(MJ) \$ IF (EJ .GT. EQSTE(MJ)) ERAT=1.0	EQST 85
ENU2=(EQSTN(MJ)+ERAT*EQSTA(MJ))*(1.-VJ)*VJ/ESUBC	EQST 86
TS1=EQSTE(MJ)*ESUBC	EQST 87
GHNU=(EQSTG(MJ)-EQSTH(MJ))/VJ**ENN	EQST 88
EX2=0. \$ IF (ENU2 .GT. -10.) EX2=EXP(ENU2)	EQST 89
TS1=TS1*(1.-EX2)	EQST 90
TS2=EQSTH(MJ)+GHNU \$ PJ=(EJ-TS1)*DJ*TS2	EQST 91
IF (EJ .GT. EMELT(MJ,1)) PJ=AMAX1(0.,PJ)	EQST 92
IF (CJ .EQ. 1.) GO TO 500	EQST 93
DPDDJ=(EJ-TS1)*(TS2+ENN*GHNU)+TS2*(EQSTE(MJ)*ESUBC-TS1)	EQST 94
1 *(EQSTN(MJ)+ERAT*EQSTA(MJ))/ESUBC*(2.*VJ-1.)*VJ	EQST 95
DPDEJ=DJ*TS2*(1.+EQSTA(MJ)*EX2*VJ*(1.-VJ))	EQST 96
IF (EQSTV(MJ) .LE. 0. .AND. EJ .GT. EQSTE(MJ)) DPDEJ=DJ*TS2	EQST 97
EX1=EX2*(1.-ENU2)	EQST 98
IF (EQSTV(MJ) .GT. 0. .AND. EJ .GT. EQSTE(MJ)) DPDEJ=DJ*TS2*(1.-	EQST 99
1 EQSTE(MJ)/EJ*(1.-EX1))	EQST 100
CSQ=DPDDJ+(EJ-TS1)*TS2/DJ*DPDEJ+AMU/DJ	EQST 101
GO TO 450	EQST 102
C EQST FOR COMPRESSED ZONES	EQST 103
300 IF (NHUG(MJ)-2) 310,320,330	EQST 104
C PUFF HUGONIOT	EQST 105
310 PH = ((EQSTS(MJ)*EMU+EQSTD(MJ))*EMU+EQSTC(MJ))*EMU	EQST 106
DPHDD = ((3.*EQSTS(MJ)*EMU+2.*EQSTD(MJ))*EMU+EQSTC(MJ))/RHOS(MJ)	EQST 107
GO TO 370	EQST 108
C MURNAGHAN HUGONIOT	EQST 109
320 PH = AMURN(MJ)*((DJ/RHOS(MJ))*BPMURN(MJ)-1.)	EQST 110
DPHDD = (EQSTC(MJ)+BPMURN(MJ)*PH)/DJ	EQST 111
GO TO 370	EQST 112
C LINEAR US-UP HUGONIOT	EQST 113
330 PH = EQSTC(MJ)*(1.-VJ)/(1.-S1(MJ)*(1.-VJ))**2	EQST 114
DPHDD = VJ/DJ*(1.+S1(MJ)*(1.-VJ))/(1.-S1(MJ)*(1.-VJ))**3	EQST 115
C COMPUTE PRESSURE DERIVATIVES AND SOUND SPEED	EQST 116
370 GF = 1.-0.5*EQSTG(MJ)*(1.-VJ)	EQST 117
PJ = PH*GF+EQSTG(MJ)*RHOS(MJ)*EJ	EQST 118
IF (CJ .EQ. 1.) GO TO 500	EQST 119
DPDDJ = DPHDD*GF-0.5*PH*EQSTG(MJ)/RHOS(MJ)/(1.+EMU)**2	EQST 120
DPDEJ = EQSTG(MJ)*RHOS(MJ)	EQST 121
CSQ = DPDDJ+PJ*DPDEJ/DJ**2+AMU/DJ	EQST 122
GO TO 450	EQST 123
C EQST FOR EXPLOSIVE (NPR = 1)	EQST 124
400 PJ = EQSTG(MJ)*DJ*EJ	EQST 125
DPDEJ=EQSTG(MJ)*DJ	EQST 126
DPDDJ=EQSTG(MJ)*EJ	EQST 127
CSQ=EQSTG(MJ)*(EJ+PJ/DJ)	EQST 128
C SOUND SPEED COMPUTATION	EQST 129

SUBROUTINE EQST (Concluded)

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450  IF (CSQ .LE. 0.) RETURN $ CQ=CSQ/(CJ*CJ) EQST 130
      CJ=CJ*(CQ/(CQ+1.))+0.25*(CQ+1.) EQST 131
      IF (CQ .LT. 0.5 .OR. CQ .GT. 2.) CJ=SQRT(CSQ) EQST 132
1005  FORMAT(* EQST: EFFECTIVE VAPORIZATION ENERGY HAS MCCLOSKEY-THOMPSON EQST 133
      1N LOG VARIATION ABOVE EQSTE*) EQST 134
1007  FORMAT(* EQST: EXPONENT IN GRUNEISEN EXPRESSION =*1PE10.3) EQST 135
1009  FORMAT(* EQSTA=*1PE10.3,* IS COEFFICIENT OF SECOND TERM ASSUMED IN EQST 136
      1 GRUNEISEN SERIES USED FOR IMPROVING EXPANSION EOS MODEL*) EQST 137
1010  FORMAT(* MURNAGHAN HUGONIOT, CONSTANTS CHANGED TO EQSTC=*1PE10.3,* EQST 138
      1, EQSTD=*1PE10.3) EQST 139
1020  FORMAT(* LINEAR US-UP HUGONIOT, CONSTANTS CHANGED TO EQSTC=*1PE10. EQST 140
      13,*, EQSTD=*1PE10.3) EQST 141
1050  FORMAT(* EXPANSION PORTION OF EQUATION OF STATE IS INCOMPLETE*) EQST 142
1055  FORMAT(* EXPANSION EOS WILL BE UNSTABLE ABOVE SUBLIMATION EQST 143
      1 ENERGY FOR CHOSEN VALUE OF EQSTA/*----- EQST 144
      2 EQSTN=*1PE10.3,*ADDITIONAL EXPONENT=*E10.3) EQST 145
500  RETURN EQST 146
      END EQST 147

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SUBROUTINE EQSTPF

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SUBROUTINE EQSTPF(NCALL,IN,M,CJ,0,E,P)
C
C      EQSTPF COMPUTES PRESSURE FROM A THREE-PHASE EQUATION OF STATE
C      DEVELOPED BY PHILCO-FORO. ROUTINE HAS TWO PARTS, ONE FOR
C      READING AND INITIALIZING AND THE OTHER FOR COMPUTING PRESSURE.
C
C      READ INPUT (NCALL=0). CALL IS FROM GENRAT.
C      INPUT - NCALL, IN, M, AND MATERIAL PROPERTY CARDS
C      OUTPUT - PRINTS CARD IMAGES, ORGANIZES DATA INTO ARRAYS
C      COMPUTE PRESSURE (NCALL=1) CALL IS FROM HSTRESS USUALLY
C      INPUT - NCALL, M, CJ, D, E
C      OUTPUT - P (CURRENT PHASE OR STATE OF MATERIAL IS AVAILABLE)
C
C      NAMED COMMON
C      REAL MU,MUM
C      COMMON /EQS/ EQSTA(6),EQSTC(6),EQSTD(6),EQSTE(6),EQSTG(6),
1 EQSTH(6),EQSTN(6),EQSTS(6),EQSTV(6),CZQ(6),CWQ(6),C2(6)
C      COMMON /MELT/ EMELT(6,5),SPH(6),THERM(6,8)
C      COMMON /RHO/ RHO(6),RHOS(6)
C      COMMON /TSR/ TSR(6,30),EXMAT(6,20),TENS(6,3)
C      COMMON /Y/ Y0(6),YAOD(6),MU(6),MUM,YADOM
C      DIMENSION A1(6),A2(6),B(6),BP(6),CI(6),CBT(6),CC(6),CV(6),O1(6),
1 DEDV(6),EBL(6),ERS(6),EC(6),EES(6),ELO(6),EO(6),EOVO(6),EPSI(6),
2 EPS2(6),ESO(6),EVO(6),HDOCT(6),PC(6),PVO(6),Tm(6),VC(6),VLO(6),
3 VO(6),VSO(6),VVO(6),WT(6),Y1(6),Y3(6),ZC(6),ZK0(6),ZKI(6),ZK2(6),
4 ZN(6),ZM(6)
C      DATA ACC, RI /1.E-4, 8.3144E7/
C
C      ***** BRANCH TO INITIALIZATION OR COMPUTATION PORTIONS
C      IF(NCALL .EQ. 1) GO TO 200
C      *****
C      REAO INPUT DATA AND INITIALIZE CONSTANTS
C      *****
C      IND = 5H
C      READ(IN,1101) Z1,CI(M),DLM,DSM,OI(M),HLB,HLM,HSM
C      WRITE(6,1101) Z1,CI(M),OLM,OSM,D1(M),HLB,HLM,HSM
C      WRITE(6,1102) INO,IN
C      READ(IN,1101) Z1,HVB,HVM,TBK,TCK,TMK,WT(M),ZKO(M)
C      WRITE(6,1101) Z1,HVB,HVM,TBK,TCK,TMK,WT(M),ZKO(M)
C      WRITE(6,1102) IND,IN
C      VO(M) = 1./RHOS(M)
C      ESO(M)=HSM
C      IF(DSM .GT. 0.) GO TO 50
C      COMPUTE -OSM- IF UNSPECIFIED
C      ERG = EQSTG(M)*RHOS(M)*ESO(M)
C      EMU = -ERG/(EQSTC(M)+ERG)
C      EMU = -ERG/(EQSTC(M)+(EQSTO(M)+EQSTS(M)*EMU)*EMU+ERG)
C      NC2=0
40 EMUO = EMU
C      NC2=NC2+1
C      IF(NC2 .GT. 20) GO TO 42
C      P = EMU*(EQSTC(M)+EMU*(EQSTD(M)+EMU*EQSTS(M))+ERG)+ERG
C      PP = EQSTC(M)+ERG+EMU*(2.*EQSTD(M)+3.*EMU*EQSTS(M))
C      EMU = EMU-P/PP
C      IF(ABS(EMU-EMUO) .GT. ACC) GO TO 40
C      GO TO 44
42 PRINT 1103,EMUO,P,PP,EMU,M
C      STOP 42
44 CONTINUE
C      VSO(M) = VO(M)/(EMU+1.)
C      GO TO 60
C      AOJUST -ESO- , -VSO- TO AGREE WITH -DSM-
50 VSO(M) = 1./DSM
C      EMU = OSM/RHOS(M)-1.
C      ESO(M) = -EMU*(EQSTC(M)+EMU*(EQSTD(M)+EMU*EQSTS(M)))/(EQSTG(M)*
1 RHOS(M)*(1.+EMU))
60 ELO(M) = ESO(M)+HLM-HSM
C      COMPUTE -DLM- IF UNSPECIFIED
C      IF(DLM .LE. 0.)DLM = 0.935/VSO(M)

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SUBROUTINE EQSTPF (Continued)

	VLO(M) = 1./DLM	EQSTPF64
	TM(M) = TMK/TCK	EQSTPF65
	TB = TBK/TCK	EQSTPF66
	ELB = HVB-HLB	EQSTPF67
C	SOLVE FOR -CL- FROM EQ. 3.21	EQSTPF68
	CL = (HLB-HLM)/(TBK-TMK)	EQSTPF69
	CV(M) = (HVB-HVM)/(TBK-TMK)	EQSTPF70
	DLTC = CV(M)-CL	EQSTPF71
C	SOLVE FOR -A1- , -A2- AND -ALPHA- FROM EQS. 3.24	EQSTPF72
	A1(M) = DLTC/R1*WT(M)	EQSTPF73
	A2(M) = (ELB-DLTC*TBK)/(R1*TCK)*WT(M)	EQSTPF74
C	SOLVE FOR -AR- FROM EQ. 3.25	EQSTPF75
	X = 36./TB+6.*TB**6-42.	EQSTPF76
	AR = (A2(M)/TB+A1(M)+0.31425*X)/(1.+0.0838*X)	EQSTPF77
	A2(M) = A2(M)-A1(M)	EQSTPF78
C	SOLVE FOR -ZC- FROM EQ. 3.27	EQSTPF79
	ZC(M) = 1./(3.72+0.26*(AR-7.))	EQSTPF80
C	SOLVE FOR -VC- FROM EQ. 3.33	EQSTPF81
	VC(M) = (1.+C1(M)*(1.-TM(M))*((1./3.)+D1(M)*(1.-TM(M)))/OLM	EQSTPF82
C	SOLVE FOR CRITICAL PRESSURE -PC- FROM EQ. 3.34	EQSTPF83
	PC(M) = ZC(M)*R1*TCK/VC(M)/WT(M)	EQSTPF84
C	SOLVE EQ. 3.6B FOR B1 = BETA, COMPUTE B,BP	EQSTPF85
	B1 = 3.	EQSTPF86
	B2 = 1.5*(1./ZC(M)-1.)	EQSTPF87
	B3 = 2.25/ZC(M)**2-5.5/ZC(M)-0.75	EQSTPF88
70	B0 = B1	EQSTPF89
	B1 = B2+SQRT(B3-1./B1)	EQSTPF90
	IF (ABS((B1-B0)/B1) .GT. ACC) GO TO 70	EQSTPF91
	B(M) = ((3.*B1-6)*B1-1.)/(B1*(3.*B1-1.))	EQSTPF92
	BP(M) = (B1-3.)/(3.*B1-1.)	EQSTPF93
C	COMPUTE -K0- , -K1- , AND -K2- (EQS. 3.7)	EQSTPF94
	IF(ZK0(M) .EQ. 0.) ZK0(M) = B1	EQSTPF95
	ZK1(M) = B1-ZK0(M)	EQSTPF96
	ZK2(M) = (1.+ZK1(M)+B1-A1(M)-A2(M))/2.	EQSTPF97
	EPS1(M) = ZC(M)*TCK*R1/WT(M)	EQSTPF98
	EPS2(M) = TCK*(CV(M)-R1/WT(M))	EQSTPF99
	EO(M) = HVB-CV(M)*TBK	EQSTP100
C	SOLVE EQ. 3.28 FOR RV TO FIND EVO, PVO, DVO, VVO	EQSTP101
	T = TM(M)	EQSTP102
	PV = EXP(A2(M)*(1.-1./T)+A1(M)*ALOG(T))	EQSTP103
	X1 = T/ZC(M)	EQSTP104
	A = ZK0(M)+ZK1(M)/T	EQSTP105
	AP = ZK2(M)*(T-1./T)	EQSTP106
C	SOLVE EQ. 4.5 FOR RV	EQSTP107
	RV = PV/X1	EQSTP108
	NC3=0	EQSTP109
80	RV1 = RV	EQSTP110
	NC3=NC3+1	EQSTP111
	IF (NC3 .GT. 20) GO TO 82	EQSTP112
	X2 = 1.-(B(M)-BP(M)*RV1)*RV1	EQSTP113
	P0 = X1*RV1/X2-(A+AP*RV1)*RV1**2	EQSTP114
	POP = X1/X2+(X1*RV1*(B(M)-2.*BP(M)*RV1))/(X2*X2)-(2.*A+3.*AP*RV1)	EQSTP115
	1*RV1	EQSTP116
	RV=AMAX1(RV1+(PV-P0)/POP,1.E-12)	EQSTP117
	IF (ABS(RV-RV1) .GT. ACC*RV .AND. ABS(RV-RV1) .GT. 1.E-12) GO TO 80	EQSTP118
	GO TO 83	EQSTP119
82	PRINT 1104,RV1,P0,POP,RV,M	EQSTP120
	STOP 72	EQSTP121
83	CONTINUE	EQSTP122
C	SOLVE EQS. 4.4C, D, AND E FOR EV, RL, EL	EQSTP123
	EV = EO(M)+EPS2(M)*T-EPS1(M)*((ZK0(M)+2.*ZK1(M)/T)-ZK2(M)*RV/T)*RV	EQSTP124
	RL = 1.+C1(M)*(1.-T)*((1./3.)+O1(M)*(1.-T))	EQSTP125
	EL = EV-EPS1(M)*PV*(1./RV-1./RL)*(A2(M)/T+A1(M)-1.)	EQSTP126
	E1 = EO(M)+ELO(M)-EL	EQSTP127
	EVO(M) = EV+E1-EO(M)	EQSTP128
	PVO(M) = PV	EQSTP129
	VVO(M) = VC(M)/RV	EQSTP130
	EO(M) = E1	EQSTP131
C	SOLVE EQ. 4.4D FOR -EC- WITH T = 1, RV = 1	EQSTP132
	EC(M) = EO(M)+EPS2(M)-EPS1(M)*(ZK0(M)+2.*ZK1(M)-ZK2(M))	EQSTP133

SUBROUTINE EQSTPF (Continued)

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DEDV(M) = (ELO(M)-ESO(M))/(VLO(M)-VSO(M))
EOVO(M)=DEDV(M)
EES(M) = VO(M)*DEDV(M)
CC(M) = (C1(M)/D1(M))*3/27.
CSO = ESO(M)/(TMK-298.)
HDCT(M) = 0.5*(CL-CSO)*TMK
CBT(M) = 0.5*(CL+CSO)*TMK
EBL(M) = ELO(M)-CSO*TMK
EBS(M) = ESO(M)-CL*TMK
Y1(M) = 2.*CBT(M)
Y3(M) = Y1(M)*(CL-CSO)*TMK
C   CONSTRUCT A FIT TO APPROXIMATE RV-T RELATION ON LV-V BOUNDARY
    T1=T=0.95
    NPART=5
    GO TO 650
100  R1=RV
    T2=T=0.9
    NPART =6
    GO TO 650
105  R2=RV
    ZN(M)= ALOG((1.-R1)/(1.-R2))/ALOG((1.-T1)/(1.-T2))
    ZM(M) = (1.-R1)/(1.-T1)**ZN(M)
    RETURN
C *****
C           CALCULATIONS TO FIND P(V,E)
C *****
C           SELECT REGION OF PHASE DIAGRAMS
200  CONTINUE
    V = 1./D
C     SELECT S, SL, L OR L, LV, AND V REGIONS
    IF (V .GE. VLO(M)) GO TO 300
C     TEST FOR COOL SOLID
    IF (E .LE. ESO(M)) GO TO 700
C *** SOLVE FOR VS ON S-SL BOUNDARY WITH ES=E
    Y2 = E-EBS(M)
    EZ = E
    NPART = I $ GO TO 600
C     SECOND BRANCH FOR SOLID MATERIAL, CONTINUE WITH SL AND L
220  IF (V .LT. VS) GO TO 700
C     TEST FOR COOL LIQUID
    IF (E .LT. ELO(M)) GO TO 750
C *** SOLVE FOR TEMP OF E AS IF E IS ON SL-L LINE
    Y2 = E-EBL(M)
    TF = (Y2+SQRT(Y2*Y2-Y3(M)))/Y1(M)
C     COMPUTE ES FOR TF
    EZ = ES = EBS(M)+CBT(M)*TF+HDCT(M)/TF
C     GO TO 600 TO GET VS ON S-SL LINE
    NPART = 2 $ GO TO 602
C     COMPUTE VLM OR SL-L LINE
250  VLM = VS+(E-ES)/DEDV(M)
    NL = I
C     SEPARATE SOLID-LIQUID AND LIQUID
    IF (V-VLM) 755,755,810
C
C *** BEGIN SWITCHING FOR L, LV, AND V REGIONS
300  IF (V .LT. VC(M)) GO TO 350
C     BRANCH FOR HIGHLY VAPORIZED MATERIAL
    IF (V .GT. VVO(M)) GO TO 900
C     COMPUTE EC(V) AT CRITICAL TEMP TO COMPARE WITH E
    ECV = EO(M)+EPS2(M)-EPSI(M)*((ZKO(M)+2.*ZK1(M))*RV-ZK2(M)*RV*RV)
C     SECOND PARTIAL ISOLATION OF V FROM LV REGION
    IF (E .GT. ECV) GO TO 900
C     COMPUTE T AND THEN EV ON LV-V LINE TO MAKE THIRD TEST FOR
C     SEPARATING LV AND V
    RV = VC(M)/V
    X1 = RV/(ZC(M)*(1.-(B(M)-BP(M)*RV)*RV))-ZK2(M)*RV**3
    X2 = -ZKO(M)*RV*RV

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EQSTP134
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EQSTP201

SUBROUTINE EQSTPF (Continued)

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X3 = (ZK2(M)*RV-ZK1(M))*RV*RV
TM1N = 0.0
IF (X1 .GT. 0.0 .AND. X3 .GT. 0.0) TM1N=SQRT(X3/X1)
FMAX = (E-ELO(M))/(EVO(M)-ELO(M))
IF (V .GT. FMAX*VVO(M)+(1.-FMAX)*VLO(M)) GO TO 990
T = 1.0
PV = EXP(A2(M)*(1.-1./T)+A1(M)*ALOG(T))
NC4=0
310 PVT = PV
NC4=NC4+1
IF (NC4 .GT. 20) GO TO 312
TA = T
PG = X1*T+X2+X3/T
PVP = PV*(A2(M)/T+A1(M))/T
PGP = AMAX1(0.,X1-X3/(T*T))
T = AMAX1(TA+(PG-PV)/(PVP-PGP),TM1N+ACC)
IF (PVP-PGP .LT. 0. ) T=TA+0.05
T = AMIN1(1.,0.8*TA+0.199)
PV = EXP(A2(M)*(1.-1./T)+A1(M)*ALOG(T))
IF (ABS((PV-PVT)/PV) .GT. ACC) GO TO 310
EV = EO(M)+EPS2(M)*T-EPS1(M)*(ZK0(M)+2.*ZK1(M)/T-ZK2(M)*RV/T)*RV
C BRANCH TO EITHER V OR LV REGIONS
IF (T .LE. TM(M)) GO TO 985
IF (E-EV) 850,900,900
312 PRINT 1105,TA,PG,PVP,PGP,T,PV,M
STOP 312
C
C *** TEST TO SEPARATE L AND LV REGIONS
C FIRST COMPUTE T ON L-LV LINE, THEN EL
350 NL = 2
IF (E .GT. EC(M)) GO TO 800
RL = VC(M)/V
X1 = (1.-RL)/D1(M)/2.
X = SQRT(X1*X1+CC(M))
T = 1.-((X-X1)**(1./3.)-(X+X1)**(1./3.))**3
C GO TO 650 TO OBTAIN EL
NPART = 1
GO TO 650
C BRANCH TO EITHER L OF LV REGIONS
375 NL = 3
IF (E-EL) 855,855,800
C *****
C BUILT-IN SUBROUTINES
C *****
C *****
C *** SOLVE FOR VS ON S-SL LINE, GIVEN ES-EZ
600 TF = (Y2+SQRT(Y2*Y2-Y3(M)))/Y1(M)
602 RGE = RHOS(M)*EQSTG(M)*EZ
DEN = EQSTC(M)+RGE
ENUM = EOVO(M)*(TF-1.)-RGE
EMU1A = 0.
EMU1B = EMUJA = ENUM/DEN
NC1=0
605 EMUJB = ENUM/(DEN+EMU1B*(EQSTD(M)+EMU1B*EQSTS(M)))
NC1=NC1+1
IF (NC1 .GT. 20) GO TO 620
EMU = (EMU1A*EMUJB-EMU1B*EMUJA)/(EMUJB-EMUJA+EMU1A-EMU1B)
IF (ABS(EMU-EMUJB) .LE. ACC) GO TO 610
EMU1A = EMU1B
EMUJA = EMUJB
EMU1B = EMU
GO TO 605
610 VS = 1./(RHOS(M)*(EMU+1.))
GO TO (220,250,805)NPART
620 PRINT 1106,TF,EZ,M,EMU1A,EMU1B
STOP 620
C

```

EQSTP202
EQSTP203
EQSTP204
EQSTP205
EQSTP206
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EQSTP265
EQSTP266
EQSTP267
EQSTP268

SUBROUTINE EQSTPF (Continued)

```

C *** SOLVE FOR P,RL,EL,RV,EV, ON LV-V BOUNDARY EQSTP269
C EQSTP270
650 PV=EXP(A2(M)*(1.-1./T)+A1(M)*ALOG(T)) EQSTP271
    X1=T/ZC(M) EQSTP272
    A=ZK0(M)+ZK1(M)/T EQSTP273
    AP=ZK2(M)*(T-1./T) EQSTP274
    PX=PV/X1 EQSTP275
    BAX=B(M)-A/X1 EQSTP276
    IF (PX*BAX .LT. -0.25 .AND. NPART .LT. 5) GO TO 653 EQSTP277
    RV=PX*(1.-PX*BAX) EQSTP278
    IF (PX*BAX .LT. -0.05) RV=PV/(X1/(1.+(-B(M)+8P(M)*RV)*RV)-(A+AP*RV EQSTP279
    1)*RV) EQSTP280
    GO TO 654 EQSTP281
653 RV=1.-ZM(M)*(1.-T)**ZN(M) EQSTP282
654 NC7=0 EQSTP283
655 RV1 = RV EQSTP284
    NC7=NC7+1 EQSTP285
    IF (NC7 .GT. 20) GO TO 670 EQSTP286
    X2 = 1.- (B(M)-8P(M)*RV)*RV EQSTP287
    P0 = X1*RV/X2-(A+AP*RV)*RV**2 EQSTP288
    POP = X1/X2+(X1*RV*(B(M)-2.*BP(M)*RV))/X2**2-(2.*A+3.*AP*RV)*RV EQSTP289
    RV = AMAX1(RV+(PV-P0)/POP,1.E-12) EQSTP290
    IF (ABS(RV-RV1).GT.ACC*RV .AND. ABS(RV-RV1).GT.1.E-12) GO TO 655 EQSTP291
    EV = EO(M)+EPS2(M)*T-EPS1(M)*((ZK0(M)+2.*ZK1(M)/T)-ZK2(M)*RV/T)*RV EQSTP292
    IF (NPART .GT. 1) RL = 1.+C1(M)*(1.-T)**(1./3.)+D1(M)*(1.-T) EQSTP293
    EL = EV-EPS1(M)*PV*(1./RV-1./RL)*(A2(M)/T+A1(M)-1.) EQSTP294
    GO TO (375,815,875,817,100,105) NPART EQSTP295
670 PRINT1109,RV,RV1,PV,P0,POP,EV,RL,EL,T,M EQSTP296
    STOP 670 EQSTP297
C ***** EQSTP298
C CALCULATIONS FOR EACH PHASE EQSTP299
C ***** EQSTP300
C EQSTP301
C *** SOLID PHASE EQSTP302
700 EMU = 1./RHOS(M)/V-1. EQSTP303
    RGE = RHOS(M)*EQSTG(M)*E EQSTP304
    P = EMU*(EQSTC(M)+EMU*(EQSTD(M)+EMU*EQSTS(M))+RGE)+RGE EQSTP305
    GO TO 1000 EQSTP306
C EQSTP307
C *** SOLID - LIQUID MIXED PHASE EQSTP308
750 FMAX = (E-ESO(M))/(ELO(M)-ESO(M)) EQSTP309
    IF (V .GT. FMAX*VLO(M)+(1.-FMAX)*VSO(M)) GO TO 990 EQSTP310
C FIND T FOR V, E IN SL REGION EQSTP311
755 EPS = E-DEDV(M)*V EQSTP312
    ES = EPS+DEDV(M)*VS EQSTP313
    Y2 = ES-EBS(M) EQSTP314
    TF = (Y2+SQRT(Y2*Y2-Y3(M)))/Y1(M) EQSTP315
    NC5=0 EQSTP316
760 TFO = TF EQSTP317
    NC5=NC5+1 EQSTP318
    IF (NC5 .GT. 20) GO TO 780 EQSTP319
    ETA = VO(M)/VS EQSTP320
    EMU = ETA-1. EQSTP321
    ESP = CBT(M)-HDCT(M)/TF**2 EQSTP322
    ETAP = -ESP*ETA**2/EES(M) EQSTP323
    RGE = RHOS(M)*EQSTG(M)*ES EQSTP324
    H = EOVO(M)*(TF-1.)-EMU*(EQSTC(M)+EMU*(EQSTD(M)+EMU*EQSTS(M))+RGE EQSTP325
    1)-RGE EQSTP326
    HP = EOVO(M)-(EQSTC(M)+EMU*(2.*EQSTD(M)+EMU*3.*EQSTS(M))+RGE)*ETA EQSTP327
    1-EQSTG(M)*RHOS(M)*ETA*ESP EQSTP328
    TF = TF-H/HP EQSTP329
    ES = EBS(M)+CBT(M)*TF+HDCT(M)/TF EQSTP330
    VS = (ES-EPS)/DEDV(M) EQSTP331
    IF (ABS(TF-TFO)/TF .GT. ACC) GO TO 760 EQSTP332
    P = EOVO(M)*(TF-1.) EQSTP333
    GO TO 1000 EQSTP334
780 PRINT 1107,TF,TFO,T,M EQSTP335
    STOP 770 EQSTP336

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SUBROUTINE EQSTPF (Continued)

C		EQSTP337
C ***	LIQUID PHASE	EQSTP338
C	SOLVE FOR PLM, VLM, ON SL-L LINE	EQSTP339
800	Y2 = E-EBL(M)	EQSTP340
	TF = (Y2+SQRT(Y2*Y2-Y3(M)))/Y1(M)	EQSTP341
	EZ = ES = EBS(M)+CBT(M)*TF+HDC(T(M))/TF	EQSTP342
C	GO TO 600 TO GET VS ON S-SL LINE	EQSTP343
	NPART = 3	EQSTP344
	GO TO 602	EQSTP345
805	VLM= VS+(E-ES)/DEDV(M)	EQSTP346
810	PLM = EOVO(M)*(TF-1.)	EQSTP347
C	SOLVE FOR PLB, VLB ON L-LV LINE	EQSTP348
	IF (NL .EQ. 3) GO TO 815	EQSTP349
	IF (E .GE. EC(M)) GO TO 820	EQSTP350
	IF (NL .EQ. 1) GO TO 812	EQSTP351
	RL = VC(M)/V	EQSTP352
	X1 = (1.-RL)/D1(M)/2.	EQSTP353
	X = SQRT(X1*X1+CC(M))	EQSTP354
	T = 1.-((X-X1)**(1./3.)-(X+X1)**(1./3.))**3	EQSTP355
C	GO TO 650 TO OBTAIN EL	EQSTP356
	NPART = 2	EQSTP357
	GO TO 650	EQSTP358
812	T = TM(M)	EQSTP359
	EL = ELO(M)	EQSTP360
C		EQSTP361
C	BEGIN ITERATION LOOP TO FIND VLB ON L-LV BOUNDARY, GIVEN E	EQSTP362
C		EQSTP363
815	TL=T \$ ETL=EL \$ TU=1.0 \$ ETU=EC(M)	EQSTP364
	TLAST = 0.5*(TU+TL)	EQSTP365
C	USE PARABOLIC ESTIMATE OF SLOPES TO OBTAIN T FOR E	EQSTP366
	S2=S23=(TU-TL)/(ETU-ETL)	EQSTP367
	IF(ETL .NE. ELO(M))	EQSTP368
	1S2 = (TL-TM(M))/(ETL-ELO(M))+S23=(TU-TM(M))/(ETU-ELO(M))	EQSTP369
	T = TL+(S2+(S23-S2)*(E-ETL)/(ETU-ETL))*(E-ETL)	EQSTP370
	TLAST = 0.5*(TU+TL)	EQSTP371
	NCB=0 \$ NPART=4	EQSTP372
816	NCB=NCB+1	EQSTP373
	IF(T .GT. TU) T=0.1*TLAST+0.9*TU	EQSTP374
	IF(T .LT. TL) T=0.1*TLAST+0.9*TL	EQSTP375
	IF(NCB .GT. 20) GO TO 827	EQSTP376
C		EQSTP377
C	GO TO 650 TO COMPUTE RL,EL,RV,EV FOR GIVEN T	EQSTP378
C		EQSTP379
	GO TO 650	EQSTP380
817	IF (ABS(E-EL) .LE. ACC*AMAX1(ABS(E),ELO(M))) GO TO 819	EQSTP381
	S12 = (T-TL)/(EL-ETL)	EQSTP382
	S23 = (TU-T)/(ETU-EL)	EQSTP383
	S2 = S12+S23-(TU-TL)/(ETU-ETL)	EQSTP384
	TLAST = T	EQSTP385
	IF (EL .LT. E) GO TO 818	EQSTP386
	T = T+(S2+(S12-S2)*(E-EL)/(ETL-EL))*(E-EL)	EQSTP387
	ETU=EL \$ TU=TLAST \$ GO TO 816	EQSTP388
818	T = T+(S2+(S23-S2)*(E-EL)/(ETU-EL))*(E-EL)	EQSTP389
	ETL=EL \$ TL=TLAST \$ GO TO 816	EQSTP390
819	VLB=VC(M)/RL	EQSTP391
	PLB=PC(M)*PV	EQSTP392
	GO TO 825	EQSTP393
C	SOLVE FOR PLB ABOVE CRITICAL POINT ON V = VC LINE	EQSTP394
820	VLB = VC(M)	EQSTP395
	RV = 1.	EQSTP396
	X1 = E-EO(M)+EPS1(M)*ZK0(M)*RV	EQSTP397
	X2 = EPS1(M)*(ZK2(M)*RV-2.*ZK1(M))*RV	EQSTP398
	T = (X1+SQRT(X1*X1-4.*EPS2(M)*X2))/(2.*EPS2(M))	EQSTP399
	PG = RV*T/(ZC(M)*(1.-(B(M)-BP(M)*RV)*RV))-(ZK0(M)+ZK1(M)/T+ZK2(M)*	EQSTP400
	1(T-1./T)*RV)*RV*RV-PVO(M)	EQSTP401
	PLB = PC(M)*PG	EQSTP402

SUBROUTINE EQSTPF (Continued)

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825  RM = 1./VLM
      RB = 1./VLB
      Z1 = (PLM-PLB)/(RM-RB)
      Z2 = (RB*PLM-RM*PLB)/(RM-RB)
      P1 = Z1/V-Z2
      Z3 = ALOG(PLM/PLB)/ALOG(RM/RB)
      Z4 = (ALOG(RB)*ALOG(PLM)-ALOG(RM)*ALOG(PLB))/ALOG(RM/RB)
      ALP2 = Z3*ALOG(1./V)-Z4
      F = (PLM/(RM-1./VLO(M))-Z3*PLM/RM)/(Z1-Z3*PLM/RM)
      F = AMIN1(1.,AMAX1(0.,F))
      P = EXP(F*ALOG(P1)+(1.-F)*ALP2)
      GO TO 1000
827  PRINT 1110,T,TMIN,TMAX,TU,TL,E,ET,ETL,ETU
      STOP 727

C
C ***      LIQUID-VAPOR MIXED PHASE
850  RL = 1.+C1(M)*(1.-T)**(1./3.)+D1(M)*(1.-T)
      EL = EV-EPS1(M)*PV*(1./RV-1./RL)*(A2(M)/T+A1(M)-1.)
C      CONSTRUCT UPPER AND LOWER BOUNDS ON E, T
C      BEGIN ITERATION LOOP FOR E WITH T AS A PARAMETER
      ETU = EV
      GO TO 860
C      ENTER FROM 375 FOR V LESS THAN VC
855  ETU = EL
860  ETL = (V-VLO(M))/(VVO(M)-VLO(M))*(EVO(M)-ELO(M))+ELO(M)
      FMAX=(E-ELO(M))/(EVO(M)-ELO(M))
      IF(V.GT. FMAX*VVO(M)+(1.-FMAX)*VLO(M)) GO TO 990
      TU = T $ TL = TM(M)
      TLAST=0.5*(TU+TL)
C      LINEAR INTERPOLATION TO ESTIMATE T
      NC6=0
      NPART=3
      T = TL+(E-ETL)*(TU-TL)/(ETU-ETL)
870  NC6=NC6+1
      IF(NC6.GT. 20) GO TO 892
      IF (T.GT. TU) T=0.1*TLAST+0.8999*TM
      IF(T.LT. TL) T=0.1*TLAST+0.8999*TL
C      GO TO 650 TO COMPUTE RL, EL, RV, EV FOR GIVEN T
      GO TO 650
875  ET = (RL*V-1.)/(RL/RV-1.)*(EV-EL)+EL
      IF(ABS(E-ET).LE. ACC*AMAX1(ABS(E),ELO(M))) GO TO 890
      TLAST=T
      IF(ABS(ET-ETL).GT.1.) S12=(T-TL)/(ET-ETL)
      IF(ABS(ETU-ET).GT. 1.) S23=(TU-T)/(ETU-ET)
      S2=S12+S23-(TU-TL)/(ETU-ETL)
      IF(ET.LT. E) GO TO 880
      T=T+(S2+(S12-S2)*(E-ET)/(ETL-ET))*(E-ET)
      ETU=ET $ TU=TLAST $ GO TO 870
880  T=T+(S2+(S23-S2)*(E-ET)/(ETU-ET))*(E-ET)
      ETL=ET $ TL=TLAST $ GO TO 870
890  P = PC(M)*(PV-PVO(M))
      GO TO 1000
892  PRINT 1108,T,TMIN,TMAX,TU,TL,E,ET,ETL,ETU
      STOP 772

C
C ***      VAPOR PHASE
900  RV = VC(M)/V
      X1 = E-E0(M)+EPS1(M)*ZK0(M)*RV
      X2 = EPS1(M)*(ZK2(M)*RV-2.*ZK1(M))*RV
      T = (X1+SQRT(X1*X1-4.*EPS2(M)*X2))/(2.*EPS2(M))
      P = PC(M)*(RV*T/(ZC(M)*(1.-(B(M)-BP(M)*RV)*RV))-(ZK0(M)+ZK1(M)/T+
1  ZK2(M)*(T-1./T)*RV)*RV-PVO(M))
      GO TO 1000
985  CONTINUE

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SUBROUTINE EQSTPF (Concluded)

C		EQSTP467
C ***	CUTOFF AT ZERO PRESSURE	EQSTP468
990	P = 0.	EQSTP469
1000	RETURN	EQSTP470
1100	FORMAT(8A10)	EQSTP471
1101	FORMAT(A10,1P7E10.3)	EQSTP472
1102	FORMAT(1H+,79X,5H IND=A2,5H, IN=I2,* READ IN EQSTPF*)	EQSTP473
1103	FORMAT(1H-,* LOC=42 IN EQSTPF*5X,* EMU0,P,PP,EMU,M= *1P5E10.3///)	EQSTP474
1104	FORMAT(1H-,* LOC=82 IN EQSTPF*5X,* RV1,P0,POP,RV,M=*1P5E10.3///)	EQSTP475
1105	FORMAT(1H-,* LOC=312 IN EQSTPF*5X,* TA,PG,PVP,PGP,T,PV,M= *1P3E10.3///)	EQSTP476
1106	FORMAT(1H-,* LOC=620 IN EQSTPF *5X,* T,EZ,M,EMU1A,EMU1B=*1P5E10.3///)	EQSTP477
1107	FORMAT(1H-,* LOC=780 IN EQSTPF *5X,* TF,TFO,T,M=*1P4E10.3///)	EQSTP478
1108	FORMAT(1H-,* LOC=892 IN EQSTPF*,5X,* T,TMIN,TMAX,TU,TL,E,ET,ETL, 1ETU *1P5E10.3/1P4E10.3///)	EQSTP479
1109	FORMAT(1H-,* LOC=670 IN EQSTPF*,5X,* RV,RV1,PV,P0,POP,EV,RL,EL,T,MEQSTP483	EQSTP482
1110	FORMAT(1H-,* LOC=827 IN EQSTPF*,5X,* T,TMIN,TMAX,TU,TL,E,ET,ETL, 1ETU *1P5E10.3/1P4E10.3///)	EQSTP484
	END	EQSTP485
		EQSTP486
		EQSTP487

SUBROUTINE ESA

C	SUBROUTINE ESA(NCALL,IN,M,C,D,E,P,OPDR,DPDE)	ESA	2
C		ESA	3
C	ROUTINE COMPUTES PRESSURE FROM SIMPLE TWO-PHASE EQUATION OF STATE.	ESA	4
C	ESA HAS TWO PARTS, CORRESPONDING TO READING AND COMPUTING	ESA	5
C		ESA	6
C	READ INPUT (NCALL=0). CALL IS FROM GENRAT.	ESA	7
C	INPUT - NCALL, IN, M, MATERIAL PROPERTY CARDS	ESA	8
C	OUTPUT - PRINTS CARO IMAGES, ORGANIZES OATA INTO ARRAYS	ESA	9
C		ESA	10
C	COMPUTE PRESSURE (NCALL=1) CALL IS FROM HSTRESS USUALLY.	ESA	11
C	INPUT - NCALL,M,C,D,E	ESA	12
C	OUTPUT - C,P,OPDE	ESA	13
C		ESA	14
C	NAMED COMMON	EQSTCOM2	
	REAL MU,MUM	EQSTCOM3	
	COMMON /EQS/ EQSTA(6),EQSTC(6),EQSTD(6),EQSTE(6),EQSTG(6),	EQSTCOM4	
1	EQSTH(6),EQSTN(6),EQSTS(6),EQSTV(6),CZQ(6),CWQ(6),C2(6)	EQSTCOM5	
	COMMON /MELT/ EMELT(6,5),SPH(6),THERM(6,8)	EQSTCOM6	
	COMMON /RHO/ RHO(6),RHOS(6)	EQSTCOM7	
	COMMON /TSR/ TSR(6,30),EXMAT(6,20),TENS(6,3)	EQSTCOM8	
	COMMON /Y/ Y0(6),YADD(6),MU(6),MUM,YADDM	EQSTCOM9	
C		ESA	16
	DIMENSION B(4,6),F1(6),F2(6),F3(6),F4(6),G1(6),G2(6),G3(6)	ESA	17
	DATA 100/1H /	ESA	18
C		ESA	19
	IF (NCALL.EQ. 1) GO TO 200	ESA	20
C	*****	*****	ESA
C	READ INPUT OATA AND INITIALIZE ARRAYS	ESA	22
C	*****	*****	ESA
	READ (IN,1100) A1,G1(M),F1(M),F2(M),P1,R1,E1	ESA	24
	WRITE (6,1100) A1,G1(M),F1(M),F2(M),P1,R1,E1	ESA	25
	WRITE (6,1121) 100,IN	ESA	26
	READ (IN,1100) A1,P2,R2,E2,P3,R3,E3	ESA	27
	WRITE (6,1100) A1,P2,R2,E2,P3,R3,E3	ESA	28
	WRITE (6,1121) 100,IN	ESA	29
C	INITIALIZE COEFFICIENTS IN EXPANSION EQUATION	ESA	30
	R0=RHOS(M)	ESA	31
	F3(M)=(2.*F1(M)-F2(M))/R0	ESA	32
	F4(M)=(F2(M)-F1(M))/R0/R0	ESA	33
	G2(M)=EQSTG(M)-G1(M) \$ G3(M)=G1(M)/R0	ESA	34
C	INITIALIZE -B- ARRAY	ESA	35
	A0=EQSTC(M)/R0	ESA	36
	A1=P1-R1*E1*(G2(M)+R1*G3(M))-R1*E1*E1*(F3(M)+R1*F4(M))	ESA	37
	A2=P2-R2*E2*(G2(M)+R2*G3(M))-R2*E2*E2*(F3(M)+R2*F4(M))	ESA	38
	A3=P3-R3*E3*(G2(M)+R3*G3(M))-R3*E3*E3*(F3(M)+R3*F4(M))	ESA	39
C	REDEFINE A TO INCLUDE DENOMINATORS	ESA	40
	R0=RHOS(M)	ESA	41
	D01=R0-R1 \$ D02=R0-R2 \$ D03=R0-R3 \$ D12=R1-R2	ESA	42
	D13=R1-R3 \$ D23=R2-R3	ESA	43
	A0=A0/(D01*D02*D03) \$ A1= A1/(D01*D01*D12*D13)	ESA	44
	A2=-A2/(D02*D02*D12*D23) \$ A3= A3/(D03*D03*D13*D23)	ESA	45
	B(1,M)=-A0*R1*R2*R3-R0*A1*R2*R3-R0*R1*A2*R3-R0*R1*R2*A3	ESA	46
	B(2,M)=R0*R1*(A2+A3)+R0*R2*(A1+A3)+R0*R3*(A1+A2)	ESA	47
1	+R1*R2*(A0+A3)+R1*R3*(A0+A2)+R2*R3*(A0+A1)	ESA	48
	B(3,M)=-R0*(A1+A2+A3)-R1*(A0+A2+A3)-R2*(A0+A1+A3)-R3*(A0+A1+A2)	ESA	49
	B(4,M)=A0+A1+A2+A3	ESA	50
	RETURN	ESA	51
C	*****	*****	ESA
C	CALCULATION OF PRESSURE AND SOUND SPEED	ESA	53
C	*****	*****	ESA
200	IF (D.LT. RHOS(M)) GO TO 300	ESA	55
C		ESA	56
C	*** COMPRESSION EQUATION OF STATE	ESA	57
	U=(D-RHOS(M))/RHOS(M)	ESA	58
	PH=U*(EQSTC(M)+U*(EQSTD(M)+U*EQSTS(M)))	ESA	59
	GG1=EQSTG(M)+U*G1(M)	ESA	60
	GF=1.-0.5*U*GG1	ESA	61
	FF=F1(M)+U*F2(M)	ESA	62

SUBROUTINE ESA (Concluded)

P = PH*GF + (GG1*D + FF*E)*E	ESA	63
DPDR = ((EQSTC(M)+U*(2.*EQSTD(M)+U*3.*EQSTS(M)))*GF	ESA	64
1 -PH*(0.5*EQSTG(M)+U*G1(M)) + (G1(M)*D + F2(M)*E)*E)/RHOS(M)	ESA	65
2 +GG1*E	ESA	66
DPDE = GG1*D + 2.*FF*E	ESA	67
GO TO 350	ESA	68
C	ESA	69
C *** EXPANSION EQUATION OF STATE	ESA	70
300 GG3=D*(G2(M)+D*G3(M))	ESA	71
FF =D*(F3(M)+D*F4(M))	ESA	72
BTERMS=B(1,M)+D*(B(2,M)+D*(B(3,M)+D*B(4,M)))	ESA	73
P = (D-RHOS(M))*BTERMS + (GG3 + FF*E)*E	ESA	74
DPDR = (G2(M)+2.*D*G3(M) + (F3(M)+ 2.*D*F4(M))*E)*E	ESA	75
1 +BTERMS + (D-RHOS(M))*(B(2,M)+D*(2.*B(3,M)+D*3.*B(4,M)))	ESA	76
DPDE = GG3 + 2.*FF*E	ESA	77
350 CSQ = DPDR + P*DPDE/D**2	ESA	78
IF (CSQ .GT. 0.) C=SQRT(CSQ)	ESA	79
RETURN	ESA	80
1100 FORMAT(A10,1P7E10.3)	ESA	81
1121 FORMAT (1H+,79X,5H IND=A2,5H, IN=I2,* -ESA-*)	ESA	82
END	ESA	83

SUBROUTINE EXPLODE

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SUBROUTINE EXPLODE (NCALL,IN,M,EHL,DHL,OOLD,PHL,SHL,FBUR,X,J,QH,
1 TIME,DTNH)
C
C   THIS SUBROUTINE FOR DETONATING FLOW HAS THREE FUNCTIONS AND
C   IS DIVIDED INTO THREE CORRESPONDING PARTS.
C   1. INITIALIZE THE MATERIAL VARIABLES AT THE TIME OF READING
C       MATERIAL PROPERTIES.
C   2. INITIALIZE THE COORDINATE ARRAYS TO SIMULATE INITIATION.
C   3. COMPUTE PROGRESS OF DETONATION DURING THE CALCULATION.
C
C       NAMED COMMON
C       REAL MU,MUM
C       COMMON /EQS/ EQSTA(6),EQSTC(6),EQSTO(6),EQSTE(6),EQSTG(6),
1 EQSTH(6),EQSTN(6),EQSTS(6),EQSTV(6),CZQ(6),CWQ(6),C2(6)
C       COMMON /MELT/ EMELT(6,5),SPH(6),THERM(6,8)
C       COMMON /RHO/ RHO(6),RHOS(6)
C       COMMON /TSR/ TSR(6,30),EXMAT(6,20),TENS(6,3)
C       COMMON /Y/ Y0(6),YADD(6),MU(6),MUM,YADDM
C
C       DIMENSION BURN(6),DET(6),DIST(6),ECJ(6),PCJ(6),QEXPL(6),VCJ(6)
C       DIMENSION EHL(1),DHL(1),PHL(1),SHL(1),FBUR(1),X(1)
C
C       IF (NCALL-2) 100,200,300
C
C       INITIALIZE MATERIAL VARIABLES
100  REAO(IN,1000)A1,QEXPL(M),BURN(M),OIST(M)
      PRINT 1010,A1,QEXPL(M),BURN(M),OIST(M)
      PRINT 1001, IN
      DET(M)=SQRT(2.*QEXPL(M)*EQSTG(M)*(EQSTG(M)+2.))
      EHL(1)=DET(M)
      VCJ(M)=(EQSTG(M)+1.)/((EQSTG(M)+2.)*RHO(M))
      ECJ(M)=2.*(EQSTG(M)+1.)*QEXPL(M)/(EQSTG(M)+2.)
      PCJ(M)=2.*RHO(M)*QEXPL(M)*EQSTG(M)
      IF (OIST(M) .EQ. 0.) PRINT 1102,QEXPL(M)
      PRINT 1100,OET(M),VCJ(M),ECJ(M),PCJ(M)
1130  FORMAT(* AMUR, H1, VOCN =*1P3E10,3)
      RETURN
C
C       INITIALIZE CELL VARIABLES
200  CONTINUE
      IF (DIST(M) .EQ. 0.) GO TO 270
      OX = X(J+1)-X(J)
      IF (DX .LE. 0.) GO TO 250
      XH=0.5*(X(J)+X(J+1))
      TBURN = (ABS(XH-BURN(M))-DIST(M)*DX)/OET(M)
      IF (TBURN .GE. 0.) GO TO 250
      FBURN = AMIN1(1.,-TBURN*OET(M)/(DIST(M)*DX))
      EHL(J)=QEXPL(M)+(ECJ(M)-QEXPL(M))*FBURN
      DHL(J)=RHO(M)/(1.-FBURN*(1.-VCJ(M)*RHO(M)))
      PHL(J)=SHL(J)=PCJ(M)*FBURN
      FBUR(J)=FBURN
250  IF (FBUR(J) .NE. 0.) PRINT 1300,J,M,EHL(J),DHL(J),PHL(J),FBUR(J)
      RETURN
270  EHL(J) = QEXPL(M)
      FBUR(J) = 1.0
      RETURN
C
C       COMPUTE DETONATION PROCESS.
300  CONTINUE
      DX=X(J+1)-X(J)
      XH=0.5*(X(J)+X(J+1))
      DH=OHL(J)
      TBURN = (ABS(XH-BURN(M))-DIST(M)*DX/2.)/DET(M)
      FBURN = AMIN1(1.,AMAX1((TIME-0.5*DTNH-TBURN)*DET(M)/(OIST(M)*DX),
1 (1.-RHO(M)/DH)/(1.-VCJ(M)*RHO(M)),FBUR(J)))
      IF (FBURN .LT. 1.E-3) RETURN
      HDV = 0.5*(1./DOLD-1./DH)
      POLD=PHL(J)

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SUBROUTINE EXPLODE (Concluded)

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    PHL(J)=EQSTG(M)*DH*(EHL(J)+POLD*HDV+QEXPL(M)*(FBURN-FBUR(J))+QH*2.*EXPLOD63
1      *HDV)/(1.-EQSTG(M)*HDV*DH)                                EXPLOD64
    EHL(J)=EHL(J)+(PHL(J)+POLD)*HDV+QEXPL(M)*(FBURN-FBUR(J))+2.*QH*HDVEXPLOD65
    PHL(J)=AMAX1(PHL(J),PCJ(M)*FBURN)                                EXPLOD66
    EHL(J)=AMAX1(EHL(J),ECJ(M)*FBURN)                                EXPLOD67
    FBUR(J)=FBURN                                                    EXPLOD68
    IF (FBURN.EQ. 1.) PRINT 1400,J,DH                                EXPLOD69
1400  FORMAT(* DETONATION COMPLETED FOR J=*I5,* WITH DENSITY =*1PE12.4)EXPLOD70
    RETURN                                                            EXPLOD71
C                                                                    EXPLOD72
1000  FORMAT(A10,7E10.3)                                            EXPLOD73
1010  FORMAT(A10,1P7E10.3)                                            EXPLOD74
1001  FORMAT(1H+,79X,* IND= , IN=*I2,* -EXPLODE-*,*,ERG/G,CM,1/CM*) EXPLOD75
1100  FORMAT(* OUTPUT OF EXPLODE, DET=*1PE10.3,*, VCJ=*1PE10.3,*, ECJEXPLOD76
1      *1PE10.3,*, PCJ=*1PE10.3)                                    EXPLOD77
1102  FORMAT(10X,*EXPLODE-CONST.VOL.EXPLOSION WITH ENERGY=*1PE10.3,* ERGEXPLOD78
1      /G*)                                                         EXPLOD79
1300  FORMAT(* EXPLODE, J=*I3,* M=*I3,* E=*1PE10.3,* D=*F10.6,* P=* EXPLOD80
1      1PE10.3,* F=*F6.3)                                           EXPLOD81
    END                                                            EXPLOD82

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SUBROUTINE EXTRA

	SUBROUTINE EXTRA	EXTRA 2
C		EXTRA 3
C	ROUTINE IS CALLED TO READ IN AUXILIARY INFORMATION FROM CARDS	EXTRA 4
C	INPUT - NONE	EXTRA 5
C	OUTPUT - ANY WORDS IN COMMON WHICH ARE READ FROM THE EXTRA CARDS	EXTRA 6
C		EXTRA 7
	INTEGER H,POROUS,PRESS,RINTER,SOLID,SPALL	PUFCOM 2
	REAL MATL,NEM,NET,NEMH,NETH	PUFCOM 3
C	MISCELLANEOUS	PUFCOM 4
	COMMON AZERO(1),CEF,CKS,DAVG,OELTIM,OISCPT(10),OOL0,DRHO,DTMAX,	PUFCOM 5
1	DTMIN,DTN,OTNH,OU,DX,EOLD,F,FAC,FIRST,J,JCYCS,JINIT,	PUFCOM 6
2	JFIN,JREZON(15),JSMAX,JSTAR,JTS,LSUB(30),M,MAXPR(30),N,NCYCS,	PUFCOM 7
3	NEDIT,NPERN,NR,NREZON,NSCRB(6),NSEPRAT,NSPALL,NTEDT,	PUFCOM 8
4	NTEX,NTR(15),POL0,P6(20),R(30),RLAST,SLAST,SMAX,TEUIT(50),	PUFCOM 9
5	TF,TIME,TJ,TREZON,TS,T6(20),ULAST,UOLO,UZERO,XLAST,XNOW,XOLD	PUFCOM10
1	,XJDIT(20)	PUFCOM11
C	HALFSTEP VALUES	PUFCOM12
	COMMON OH,DHLAST,OUH,EH,PH,RH,RHLAST,SH,SHLAST,UH,UHLAST,XH,XHLAST	PUFCOM13
1	,NEMH,NETH	PUFCOM14
C	CONDITION INOICATORS	PUFCOM15
	COMMON INF,LINTER,MIRROR,NORMAL,POROUS,PRESS,RINTER,SOLID,SPALL	PUFCOM16
C	CELL LAYOUT	PUFCOM17
	COMMON DXX(30),JBND(30),JMAT(30),NAUTO,MATL(6,2),NLAYER,NMTRLS,	PUFCOM18
1	THK(30)	PUFCOM19
C	COORDINATE ARRAYS	PUFCOM20
	COMMON/COORD/X(200),X0(200),CHL(200),OHL(200),DPO0(200),OPDE(200),	COORDC02
1	EHL(200),H(200,3),NEM(200),NET(200),PHL(200),RHL(200),SOT(200),	COORDC04
2	SHL(200),T(200),U(200),YHL(200),ZHL(200)	COORDC05
	COMMON/NSC/A(5000)	NSCCOM 2
C	NAMEO COMMON	EQSTCOM2
	REAL MU,MUM	EQSTCOM3
	COMMON /EQS/ EQSTA(6),EQSTC(6),EQSTD(6),EQSTE(6),EQSTG(6),	EQSTCOM4
1	EQSTH(6),EQSTN(6),EQSTS(6),EQSTV(6),CZQ(6),CWQ(6),C2(6)	EQSTCOM5
	COMMON /MELT/ EMELT(6,5),SPH(6),THERM(6,8)	EQSTCOM6
	COMMON /RHO/ RHO(6),RHOS(6)	EQSTCOM7
	COMMON /TSR/ TSR(6,30),EXMAT(6,20),TENS(6,3)	EQSTCOM8
	COMMON /Y/ Y0(6),YADD(6),MU(6),MUM,YAODM	EQSTCOM9
	COMMON /INO/ IEOS(6),INDK(20),NALPHA,NCMP(6),NFR(6),NPOR(6),	INDCOM 2
1	NDS(6),NPR(6),NCON(6),NVAR(6)	INDCOM 3
	COMMON /RAD/ SSTOP(5),START(5),SDURM,SSTOPM,NSPEC,SSJ,JSS,IPLOT(4)	RAOCOM 2
1	,XMAX(4),XMIN(4),YMAX(4),YMIN(4),IA(7),ITITLE(24),NARZ,TARZ	RAOCOM 3
C		EXTRA 14
	NAMelist/NLIST/ DTMAX,JCYCS,JINIT,JFIN,LSUB,MAXPR,NEDIT,NSPALL,	EXTRA 15
1	P6,TREZON,TS,T6,UZERO,	EXTRA 16
2	X,CHL,DHL,DPOE,DPOE,EHL,H,NEM,NET,PHL,RHL,SHL,T,U,YHL,ZHL,	EXTRA 17
3	JBND,JMAT,NLAYER,	EXTRA 18
4	EQSTA,EQSTC,EQSTD,EQSTE,EQSTG,EQSTH,EQSTS,EQSTV,CZQ,CWQ,C2,	EXTRA 19
5	EMELT, RHO,RHOS, TSR,EXMAT,TENS, Y0,YADD,MU,	EXTRA 20
6	NCMP,NFR,NPOR,NOS,NPR,NCON,	EXTRA 21
7	SSTOP,START,SOURM	EXTRA 22
8	,EQSTN	EXTRA 23
C		EXTRA 24
C		EXTRA 25
	IN=5 \$ JO=6	EXTRA 26
	REWIND 7	EXTRA 27
	NREC=0	EXTRA 28
10	READ (IN,902) (A(I),I=1,9)	EXTRA 29
	IF (EOF(IN)) 19,I5	EXTRA 30
15	IF (A(I) .EQ. 2H \$) GO TO 18	EXTRA 31
	WRITE (JO,902) (A(I),I=1,9)	EXTRA 32
	WRITE (JO,901)	EXTRA 33
	WRITE (7,902) (A(I),I=1,9)	EXTRA 34
	IF (A(1) .EQ. 2H \$) NREC=NREC+1	EXTRA 35
	GO TO 10	EXTRA 36
18	WRITE (JO,902) (A(I),I=1,9)	EXTRA 37
	GO TO 20	EXTRA 38

SUBROUTINE EXTRA (Concluded)

19	WRITE (J0,903)	EXTRA 39
20	REWIND 7	EXTRA 40
	IF (NREC .LE. 0) GO TO 35	EXTRA 41
	DO 25 NRC=1,NREC	EXTRA 42
25	READ (7,NLIST)	EXTRA 43
35	CONTINUE	EXTRA 44
	RETURN	EXTRA 45
901	FORMAT(1H+,79X,* INPUT FROM -EXTRA- ROUTINE*)	EXTRA 46
902	FORMAT (A2,A8,7A10)	EXTRA 47
903	FORMAT(* EOF ENCOUNTERED BY EXTRA*)	EXTRA 48
	END	EXTRA 49

SUBROUTINE FMELT

	SUBROUTINE FMELT(LS,M,EN,FM,FG,X,MSAVE)	FMELT	2
C	SUBROUTINE COMPUTES THE THERMAL STRENGTH	FMELT	3
C	AND MODULUS REDUCTION FACTORS FM AND FG	FMELT	4
C	LS = -1 INITIALIZE FOR NOMINAL VALUES OF FMELT AND GMELT	FMELT	5
C	0 INITIALIZE FOR STRENGTH (FM)	FMELT	6
C	1 INITIALIZE FOR MODULUS (FG)	FMELT	7
C	2 COMPUTE FOR STRENGTH	FMELT	8
C	3 COMPUTE FOR MODULUS	FMELT	9
C	4 COMPUTE FOR BOTH STRENGTH AND MODULUS	FMELT	10
C	M MATERIAL NUMBER	FMELT	11
C	EN DIMENSIONAL ENERGY	FMELT	12
C	X INPUT ARRAY FOR INITIALIZING PARAMETERS	FMELT	13
C	ZERO TO 3 PARABOLIC REGIONS MAY BE USED	FMELT	14
C	INPUT VALUES	FMELT	15
C	NO. 1 2 3 4 5 6 7 8	FMELT	16
C	ZERO MELT	FMELT	17
C	ONE MELT DF1	FMELT	18
C	TWO MELT E1 DF1 F1 DF2	FMELT	19
C	THREE MELT E1 DF1 F1 E2 DF2 F2 DF3	FMELT	20
	DIMENSION E(6,6),F(6,18),NREG(6,2),X(7)	FMELT	21
	IF (LS.GT. 1) GO TO 200	FMELT	22
	IF (LS .GE. 0) GO TO 30	FMELT	23
	LS=NREG(M,1)=NREG(M,2)=0	FMELT	24
	X(1)=EN \$ X(2)=0.35 \$ X(3)=0.15 \$ X(4)=0.25 \$ X(5)=-0.06	FMELT	25
	X(7)=0.	FMELT	26
30	IF (MSAVE .EQ. M) GO TO 150	FMELT	27
C	INITIALIZE IN REGION 1	FMELT	28
50	EN = X(1)	FMELT	29
	IF (X(1) .GT. 0. .AND. (X(2) .NE. 0. .OR. X(4) .NE. 0.))	FMELT	30
	1 GO TO 60	FMELT	31
	E(M,1+LS*3)=X(1)	FMELT	32
	NREG(M,LS+1)=-1	FMELT	33
	RETURN	FMELT	34
60	NIN = 9 *LS	FMELT	35
	IF (X(4) .NE. 0.) GO TO 100	FMELT	36
	NR = 1	FMELT	37
	F(M,1+NIN) = 1.	FMELT	38
	F(M,2+NIN)=(-1.+4.*X(2))/X(1)	FMELT	39
	F(M,3+NIN)=-4.*X(2)/X(1)**2	FMELT	40
	E(M,1+3*LS) = X(1)	FMELT	41
	NREG(M,LS+1)=1	FMELT	42
	IF (ABS(X(2)) .GT. 0.251) GO TO 500	FMELT	43
	RETURN	FMELT	44
100	NR=1	FMELT	45
	IF (X(2) .LT. 1.) X(2)=X(2)*X(1)	FMELT	46
	F(M,1+NIN) = 1.	FMELT	47
	F(M,2+NIN) =(X(4)-1. +4.*X(3))/X(2)	FMELT	48
	F(M,3+NIN) =-4.*X(3)/X(2)**2	FMELT	49
	E(M,1+LS*3) =X(2)	FMELT	50
	NIN = NIN+3	FMELT	51
	IF (X(7) .NE. 0) GO TO 120	FMELT	52
	NR = 2	FMELT	53
C	INITIALIZE IN REGION 2	FMELT	54
	F(M,1+NIN)=X(4)-X(2)/(X(1)-X(2))*(-X(4)+4.*X(5)*X(1)/	FMELT	55
1	(X(1)- X(2)))	FMELT	56
	F(M,2+NIN)=(-X(4)+4.*X(5)*(X(2)+X(1))/(X(1)-X(2)))/(X(1)-X(2))	FMELT	57
	F(M,3+NIN)=-4.*X(5)/(X(1)-X(2))**2	FMELT	58
	E(M,2+LS*3) = X(1)	FMELT	59
	NREG(M,LS+1) = 2	FMELT	60
	IF (ABS(X(5)) .GT. 0.25 * X(4)+1.E-4) GO TO 500	FMELT	61
	IF (ABS(X(3)) .GT. 0.25*(1.-X(4))+1.E-4) GO TO 500	FMELT	62
	RETURN	FMELT	63
120	NR=2	FMELT	64
	IF (X(5) .LT. 1.) X(5) = X(5) *X(1)	FMELT	65
	F(M,1+NIN)= X(4)-X(2)/(X(5)-X(2))*(X(7)-X(4) +4.*X(6)/(X(5)-X(2))	FMELT	66
1	*X(5))	FMELT	67
	F(M,2+NIN)= (X(7)-X(4)+4.*X(6)*(X(5)+X(2))/(X(5)-X(2)))/	FMELT	68
1	(X(5)-X(2))	FMELT	69
	F(M,3+NIN)=-4.*X(6)/(X(5)-X(2))**2	FMELT	70
	E(M,2+LS*3)=X(5)	FMELT	71
	E(M,3+LS*3) = X(1)	FMELT	72
	MSAVE = M	FMELT	73
	X7 = X(7)	FMELT	74
	X5 = X(5)	FMELT	75
	IF (ABS(X(6)) .GT. 0.25 *(X(4)-X(7))+1.E-4) GO TO 500	FMELT	76

SUBROUTINE FMELT (Concluded)

	IF (ABS(X(3)) .GT. 0.25*(1.-X(4))+1.E-4) GO TO 500	FMELT	77
	RETURN	FMELT	78
C	INITIALIZE FOR THE THIRD REGION	FMELT	79
150	NR = 3	FMELT	80
	NIN = 9*LS + 6	FMELT	81
	EM = E(M,3+LS*3)	FMELT	82
	F(M,1+NIN) = X7-X5/(EM-X5)*(-X7+4.*X(1)*EM/(EM-X5))	FMELT	83
	F(M,2+NIN) = (-X7+4.*X(1)*(EM+X5)/(EM-X5))/(EM-X5)	FMELT	84
	F(M,3+NIN) = -4.*X(1)/(EM-X5)**2	FMELT	85
	NREG(M,LS+1) = 3	FMELT	86
	MSAVE = 0	FMELT	87
	IF (ABS(X(1)) .GT. 0.25 *X7+1.E-4) GO TO 500	FMELT	88
	RETURN	FMELT	89
C	*****	FMELT	90
C	COMPUTATION OF STRENGTH REDUCTION FUNCTION, FM	FMELT	91
200	CONTINUE	FMELT	92
	IF (LS .NE. 3) GO TO 250	FMELT	93
	IF (NREG(M,2) .NE. 0) GO TO 350	FMELT	94
250	NN = NREG(M,1)	FMELT	95
	IF (NN .LE. 0 .AND. EN .LT. E(M,1)) GO TO 255	FMELT	96
	IF (EN .GT. 0.) GO TO 260	FMELT	97
255	FM = 1.0	FMELT	98
	GO TO 300	FMELT	99
260	IF (NN .LE. 0) GO TO 265	FMELT	100
	IF (EN .LT. E(M,NN)) GO TO 275	FMELT	101
265	FM = 0.	FMELT	102
	GO TO 300	FMELT	103
275	N = 0	FMELT	104
280	N = N + 1	FMELT	105
	IF (EN.GE. E(M,N) .AND. N .LT. NN) GO TO 280	FMELT	106
	NIN = 3 * (N-1)	FMELT	107
	FM = F(M,1+NIN) + (F(M,2+NIN) + F(M,3+NIN)*EN)*EN	FMELT	108
300	IF (LS - 3) 400, 320, 310	FMELT	109
310	IF (NREG(M,2) .NE. 0) GO TO 350	FMELT	110
320	F0 = FM	FMELT	111
	GO TO 400	FMELT	112
C	COMPUTATION OF MODULUS REDUCTION FUNCTION, F0	FMELT	113
350	NN=NREG(M,2)	FMELT	114
	IF (NN .LE. 0 .AND. EN .LT. E(M,4)) GO TO 355	FMELT	115
	IF (EN .GT. 0.) GO TO 360	FMELT	116
355	F0 = 1.0	FMELT	117
	GO TO 400	FMELT	118
360	IF (NN .LE. 0) GO TO 365	FMELT	119
	IF (EN .LT. E(M,NN+3))GO TO 375	FMELT	120
365	F0 = 0.	FMELT	121
	GO TO 400	FMELT	122
375	N = 0	FMELT	123
380	N = N+1	FMELT	124
	IF (EN .GE. E(M,N+3) .AND. N .LT. NN) GO TO 380	FMELT	125
	NIN = 3*(N-1)+9	FMELT	126
	F0 = F(M,1+NIN)+(F(M,2+NIN) +F(M,3+NIN) * EN) *EN	FMELT	127
400	RETURN	FMELT	128
500	PRINT 1500, NR	FMELT	129
1500	FORMAT (33HOERROR IN FMELT, SLOPE IN REGION 13,	FMELT	130
	1 51H IS POSITIVE BECAUSE CURVE OFFSET EXCEEDS (F1-F2)/4)	FMELT	131
	RETURN	FMELT	132
	END	FMELT	133

SUBROUTINE GENRAT

	SUBROUTINE GENRAT	GENRAT	2
C		GENRAT	3
C	READS INPUT DATA AND INITIALIZES ARRAYS	GENRAT	4
C	* READS INPUT CARDS, EXCEPT FOR RADIATION INFORMATION	GENRAT	5
C	* COMPUTES COORDINATE LAYOUT	GENRAT	6
C	* INITIALIZES DENSITY, ENERGY, YIELD, SOUND SPEED, SPALL	GENRAT	7
C	STRENGTH, CONDITION INDICATORS, PARTICLE VELOCITY	GENRAT	8
C	* PRINTS INITIAL LAYOUT FOR NON-RADIATION PROBLEMS	GENRAT	9
C		GENRAT	10
	INTEGER H,POROUS,PRESS,RINTER,SOLID,SPALL	PUFCOM	2
	REAL MATL,NEM,NET,NEMH,NETH	PUFCOM	3
C	MISCELLANEOUS	PUFCOM	4
	COMMON AZERO(1),CEF,CKS,DAVG,DELTIM,DISCPT(10),DOLD,DRHO,DTMAX,	PUFCOM	5
1	DTMIN,DTN,DTNH,DU,DX,EOLD,F,FAC,FIRST,J,JCYCS,JINIT,	PUFCOM	6
2	JFIN,JREZON(15),JSMAX,JSTAR,JTS,LSUB(30),M,MAXPR(30),N,NCYCS,	PUFCOM	7
3	NEDIT,NPERN,NR,NREZON,NSCRB(6),NSEPRAT,NSPALL,NTEDT,	PUFCOM	8
4	NTEX,NTR(15),POLD,P6(20),R(30),RLAST,SLAST,SMAX,TEDIT(50),	PUFCOM	9
5	TF,TIME,TJ,TREZON,TS,T6(20),ULAST,UOLD,UZERO,XLAST,XNOW,XOLD	PUFCOM	10
1	,XJDIT(20),MS	PUFCOM	11
C	HALFSTEP VALUES	PUFCOM	12
	COMMON DH,DHLAST,DUH,EH,PH,RH,RHLAST,SH,SHLAST,UH,UHLAST,XH,XHLAST	PUFCOM	13
1	,NEMH,NETH	PUFCOM	14
C	CONDITION INDICATORS	PUFCOM	15
	COMMON INF,LINTER,MIRROR,NORMAL,POROUS,PRESS,RINTER,SOLID,SPALL	PUFCOM	16
C	CELL LAYOUT	PUFCOM	17
	COMMON DXX(30),JBND(30),JMAT(30),NAUTO,MATL(6,2),NLAYER,NMTRLS,	PUFCOM	18
1	THK(30)	PUFCOM	19
C		PUFCOM	20
C	NAMED COMMON	EQSTCOM	2
	REAL MU,MUM	EQSTCOM	3
	COMMON /EQS/ EQSTA(6),EQSTC(6),EQSTD(6),EQSTE(6),EQSTG(6),	EQSTCOM	4
1	EQSTH(6),EQSTN(6),EQSTS(6),EQSTV(6),CZQ(6),CWQ(6),C2(6)	EQSTCOM	5
	COMMON /MELT/ EMELT(6,8),GMELT(6,8),SPH(6),THERM(6,8)	EQSTCOM	6
	COMMON /RHO/ RHO(6),RHOS(6)	EQSTCOM	7
	COMMON /TSR/ TSR(6,30),EXMAT(6,20),TENS(6,3)	EQSTCOM	8
	COMMON /Y/ YO(6),YADD(6),MU(6),MUM,YADDM	EQSTCOM	9
C	COORDINATE ARRAYS	COORDCOM	2
	COMMON/COORD/X(200),XO(200),CHL(200),DHL(200),DPDD(200),DPDE(200),	COORDCOM	3
1	EHL(200),H(200,3),NEM(200),NET(200),PHL(200),RHL(200),SDT(200),	COORDCOM	4
2	SHL(200),T(200),U(200),YHL(200),ZHL(200)	COORDCOM	5
	COMMON/NSC/A(5000)	NSCCOM	2
	COMMON /JED/JEDIT(100),JNUM(100),JTYP(100),NAME2(40),JEDSIZ,	JEDCOM	2
1	MODLUS,NERR,NJEDIT,NTAPE	JEDCOM	3
	COMMON /IND/ IEOS(6),INDK(20),NALPHA,NCMP(6),NFR(6),NFOR(6),	INDCOM	2
1	NDS(6),NPR(6),NCON(6),NVAR(6)	INDCOM	3
	COMMON /RAD/ SSTOP(9),START(9),SDURM,SSTOPM,NSPEC,SSJ,JSS,IPLDT(4)	RADCOM	2
1	,XMAX(4),XMIN(4),YMAX(4),YMIN(4),IA(7),ITITLE(24),NARZ,TARZ	RADCOM	3
	COMMON /PES/ LVMAX,LVTOT,LVAR(200),COM(4000)	GENRAT	18
C		GENRAT	19
	COMMON /ESC/ ESC(6,20)	GENRAT	20
	DIMENSION DELFIN(30,5),DELX(30,5),TH(30,5),NCELLS(30,5),NZONES(30)	GENRAT	21
C	INTEGER HH	GENRAT	22
		GENRAT	23
C	EQUIVALENCE (DELFIN,H(1)),(DELX,H(151)),(TH,H(301)),	GENRAT	24
1	(NCELLS,H(451)),(NZONES,H(601))	GENRAT	25
C		GENRAT	26
C		GENRAT	27
16	FORMAT (1H1,10A10//	GENRAT	28
1	J DX X(J) U(J) YHL(J) CHL(J) DHL(J) 131H	GENRAT	29
2	T(J) ZHL(J) EHL(J) MATERIAL COND J	GENRAT	30
3	/102H CM CM CM/SEC DYN/CM2 CM/SEC GM/C	GENRAT	31
	4M3 DYN/CM2 GM/CM2 ERG/GM)	GENRAT	32
17	FORMAT(14,1P9E10.3,2X,A9,3R2,15)	GENRAT	33
18	FORMAT(29H TIME TO COMPLETE GENRAT IS F10.3,9H SECONDS.)	GENRAT	34
19	FORMAT(A4,A5,1X,1P7E10.3)	GENRAT	35
1019	FORMAT(A4,A5,1X,7E10.3)	GENRAT	36
1020	FORMAT(A10,7E10.3)	GENRAT	37
1021	FORMAT(2(A10,E10.3),A10,110,A10,E10.3)	GENRAT	38
1025	FORMAT(2(A10,110),2(A10,E10.3))	GENRAT	39
20	FORMAT(A10,1P7E10.3,A5,A2,A5,12,3A10,A7)	GENRAT	40
21	FORMAT(2(A10,1PE10.3),A10,110,A10,1PE10.3,A5,A2,A5,12,3A10,A7)	GENRAT	41
22	FORMAT(A10,14I5,A5,A2,A5,12,3A10,A7)	GENRAT	42
23	FORMAT(4(A10,110),A5,A2,A5,12,3A10,A7)	GENRAT	43
24	FORMAT (10A1)	GENRAT	44
25	FORMAT(2(A10,110),2(A10,1PE10.3),A5,A2,A5,12,3A10,A7)	GENRAT	45

SUBROUTINE GENRAT (Continued)

26	FORMAT(A1,R9,7A10,A5,A2,A5,I2,3A10,A7)	GENRAT	46
27	FORMAT(1H+,79X,A5,A2,A5,I2,3A10,A7)	GENRAT	47
30	FORMAT(8A10)	GENRAT	48
31	FORMAT(1H1,25X,26H**** SRI PUFF 8 **** /)	GENRAT	49
41	FORMAT(1H1)	GENRAT	50
50	FORMAT(A10,* BOUNDARY AT *A5,* SURFACE*)	GENRAT	51
1062	FORMAT(2A4,I2,I10,3(2A5,E10.3))	GENRAT	52
1064	FORMAT(2A5,I10,3(2A5,E10.3))	GENRAT	53
1073	FORMAT(2(A10,I10),A10,E10.3,A10,10I1)	GENRAT	54
1075	FORMAT(8E10.3)	GENRAT	55
1090	FORMAT(A1,A9,2A10,E10.3,2(A7,3I1),A7,I3,A8,I2)	GENRAT	56
62	FORMAT(2A4,I2,I10,3(2A5,1PE10.3),A5,A2,A5,I2,3A10,A7)	GENRAT	57
64	FORMAT(2A5,I10,3(2A5,1PE10.3),A5,A2,A5,I2,3A10,A7)	GENRAT	58
66	FORMAT(A10,I10,A10,10I5,A5,A2,A5,I2,3A10,A7)	GENRAT	59
67	FORMAT(86H0 **** ABORT FOLLOWING LINE DOES NOT FIT YIELD, MELT,	GENRAT	60
	1 VISCOSITY, OR SPALL CATEGORIES/8A10)	GENRAT	61
69	FORMAT()	GENRAT	62
73	FORMAT(2(A10,I10),A10,1PE10.3,A10,10I1)	GENRAT	63
75	FORMAT(1P8E10.3)	GENRAT	64
80	FORMAT(10X,14I5)	GENRAT	65
90	FORMAT(A1,A9,2A10,1PE10.3,2(A7,3I1),A7,I3,A8,I2,A5,A2,A5,I2,3A10,	GENRAT	66
	1 A7)	GENRAT	67
96	FORMAT(31H ERROR JFIN EXCEEDS 301, JFIN=14)	GENRAT	68
C		GENRAT	69
97	FORMAT(*1 DATA BANK WITH HEADING -- *A10,*-- ON FILE*	GENRAT	70
	1 I2/)	GENRAT	71
98	FORMAT(*0 DATA BANK WITH HEADING -- *A10,*-- ON FILE*I2/)	GENRAT	72
100	D0 101 I=1,456	GENRAT	73
101	AZER0(I)=0.	GENRAT	74
	D0 103 I=1,4000	GENRAT	75
103	X(I)=0.	GENRAT	76
	D0 105 I=1,5000	GENRAT	77
105	A(I)=0.	GENRAT	78
	D0 109 I=1,72	GENRAT	79
109	EQSTA(I)=0.	GENRAT	80
	D0 111 I=1,150	GENRAT	81
111	EMELT(I)=0.	GENRAT	82
	D0 113 I=1,318	GENRAT	83
113	TSR(I)=0.	GENRAT	84
	D0 115 I=1,18	GENRAT	85
115	YO(I)=0.	GENRAT	86
	D0 117 I=1,26	GENRAT	87
117	IEOS(I)=0	GENRAT	88
	D0 119 I=1,23	9/12/79	2
119	SSTOP(I)=0.	GENRAT	90
	LVTOT=4000	GENRAT	91
	LL=LVTOT+200	GENRAT	92
	D0 121 I=1,LL	GENRAT	93
121	LVAR(I)=0	GENRAT	94
	JSMAX=1	GENRAT	95
	CALL SECOND(FIRST)	GENRAT	96
	LINTER=5R L \$ NORMAL=5R N \$ POROUS=PRESS=5R P	GENRAT	97
	MIRROR=5R M \$ RINTER=5R R \$ SOLID =SPALL=5R S	GENRAT	98
	INF=5R I	GENRAT	99
	AHEAD=9HHEADING \$ BHEAD=1H \$ DISCPT(1)=10H DATE =	GENRAT	100
	IDD=1H \$ NIND=5H IND= \$ NIN=5H, IN=	GENRAT	101
	NAT=10H SEC \$ NBT=10H , , , CM, \$ NCT=10H , , , CM/	GENRAT	102
	NDT=10HSEC \$ N5T=10H G/CM3 \$ NFT=10H DYN/CM2, =	GENRAT	103
	NGT=10H, ERG/G, \$ NHT=10H , DYN/CM2 \$ NIT=10H, ERG/G	GENRAT	104
	NJT=10H DYN/CM2, \$ NKT=10H ERG/G, \$ NLT=10H CM, CM,	GENRAT	105
	IN = 5 \$ OUT = 6	GENRAT	106
	CALL DATE(DISCPT(2))	GENRAT	107
C		GENRAT	108
C	**** READ AND PRINT DATA ****	GENRAT	109
C		GENRAT	110
152	READ (5,30) (ITITLE(I),I=1,8)	GENRAT	111
C	CHECK FOR END OF LAST DATA DECK	GENRAT	112
	IF (EOF(5)) 153,154	GENRAT	113
153	STOP 70001	GENRAT	114
154	IF (ITITLE(1) .NE. 5H DATA .AND. ITITLE(1) .NE. 9H ABS DATA) GO TO	GENRAT	115
	1 157	GENRAT	116
	J0=4	GENRAT	117
	IF (ITITLE(1) .EQ. 9H ABS DATA) J0=2	GENRAT	118
	IF (ITITLE(2) .EQ. IDD) PRINT 98,ITITLE(1),J0	GENRAT	119
	IF (ITITLE(2) .NE. IDD) PRINT 97,ITITLE(1),J0	GENRAT	120

SUBROUTINE GENRAT (Continued)

155	READ (5,30)(A(I),I=1,8)	GENRAT 121
	IF (EOF(5)) 152,156	GENRAT 122
156	WRITE (J0,30)(A(I),I=1,8)	GENRAT 123
	IF (ITITLE(2) .NE. IDD) WRITE (6,30) (A(I),I=1,8)	GENRAT 124
	GO TO 155	GENRAT 125
157	DECODE (80,26,ITITLE) IND,(DISCPT(1),I=3,10)	GENRAT 126
	WRITE (6,31)	GENRAT 127
	WRITE (6,30) DISCPT(1),DISCPT(2)	GENRAT 128
	WRITE (6,26) IDD,(DISCPT(1),I=3,10),NIND,IND,NIN,IN	GENRAT 129
	IN=5	GENRAT 130
	IF (IND .EQ. IDD) GO TO 158	GENRAT 131
	IF (IND .EQ. 1HD) GO TO 190	GENRAT 132
C	ACTIVATE PROCEDURE FOR READING FROM TAPE 4	GENRAT 133
	IN=4 \$ CALL REDR(AHEAD,DISCPT(10),IN,2)	GENRAT 134
	READ (IN,26) A1	GENRAT 135
158	READ (IN,26) INDC,(A(I),I=1,8)	GENRAT 136
	IF (INDC .NE. 1HC) GO TO 159	GENRAT 137
	WRITE (6,26) IDD,(A(I),I=1,8),NIND,IDD,NIN,IN	GENRAT 138
	GO TO 158	GENRAT 139
159	DECODE (80,23,A) A1,NTEDT,A2,NJEDIT,A3,NREZON,A4,NALPHA	GENRAT 140
	IF (NALPHA .EQ. 0) NALPHA=1	GENRAT 141
	WRITE (6,23) A1,NTEDT,A2,NJEDIT,A3,NREZON,A4,NALPHA,NIND,IDD,	GENRAT 142
	1 NIN,IN	GENRAT 143
	IF (NTEDT .EQ. 0) GO TO 170	GENRAT 144
	DO 165 NT=1,NTEDT,7 \$ NZ=NT-1	GENRAT 145
	READ (IN,1020) A(NT),(TEDIT(I+NZ),I=1,7)	GENRAT 146
165	WRITE (6,20) A(NT),(TEDIT(I+NZ),I=1,7),NIND,IDD,NIN,IN,NAT	GENRAT 147
170	IF (NJEDIT .EQ. 0) GO TO 175	GENRAT 148
	NZ=8*NJEDIT	GENRAT 149
	READ (IN,30) (A(4000+I),I=1,NZ)	GENRAT 150
	WRITE (6,30) (A(4000+I),I=1,NZ)	GENRAT 151
	WRITE (6,27) NIND,IDD,NIN,IN	GENRAT 152
175	IF (NREZON) 178,180,177	GENRAT 153
177	READ (IN,22) A1,(NTR(I),I=1,NREZON)	GENRAT 154
	WRITE (6,22) A1,(NTR(I),I=1,14),NIND,IDD,NIN,IN	GENRAT 155
	READ (IN,22) A1,(JREZON(I),I=1,NREZON)	GENRAT 156
	WRITE (6,22) A1,(JREZON(I),I=1,14),NIND,IDD,NIN,IN	GENRAT 157
	GO TO 180	GENRAT 158
178	READ(IN,1021)A1,DTMAX,A2,TREZON,A3,NARZ,A4,TARZ	GENRAT 159
	WRITE(6,21)A1,DTMAX,A2,TREZON,A3,NARZ,A4,TARZ,NIND,IDD,NIN,IN,NAT	GENRAT 160
180	READ(IN,1025)A1,NEDIT,A2,JCYCS,A3,CKS,A4,TS	GENRAT 161
	WRITE (6,25) A1,NEDIT,A2,JCYCS,A3,CKS,A4,TS,NIND,IDD,NIN,IN,NBT,	GENRAT 162
	1 NAT	GENRAT 163
	NPERN=1	GENRAT 164
	IF (NEDIT .GT. 0 .OR. JCYCS .EQ. 0) GO TO 190	GENRAT 165
	NEDIT=MAX(1,-NEDIT)	GENRAT 166
	READ (IN,22) A1,(MAXPR(I),I=1,14)	GENRAT 167
	WRITE (6,22) A1,(MAXPR(I),I=1,14),NIND,IDD,NIN,IN	GENRAT 168
190	READ(IN,1073)A1,NMTRLS,A2,MATFL,A3,UZER0,A4,IPL0T,NSCRB	GENRAT 169
	WRITE (6,73) A1,NMTRLS,A2,MATFL,A3,UZER0,A4,IPL0T,NSCRB	GENRAT 170
	WRITE(6,27) NIND,IDD,NIN,IN,NCT,NDT	GENRAT 171
	IIPLOT=0	GENRAT 172
	DO 191 I=1,4	GENRAT 173
	IIPLOT=IIPLOT+IPL0T(I)	GENRAT 174
	IF (IPL0T(I) .EQ. 0) GO TO 191	GENRAT 175
	READ(IN,1020)A1,XMAX(I),XMIN(I),YMAX(I),YMIN(I)	GENRAT 176
	WRITE (6,20) A1,XMAX(I),XMIN(I),YMAX(I),YMIN(I)	GENRAT 177
191	CONTINUE	GENRAT 178
	IF (IIPLOT .EQ. 0) GO TO 192	GENRAT 179
	READ (IN,22) A1,IA	GENRAT 180
	WRITE (6,22) A1,IA	GENRAT 181
192	CONTINUE	GENRAT 182
	IF (IND .EQ. 1HX) CALL EXTRA	GENRAT 183
C		GENRAT 184
C	**** M-LOOP ****	GENRAT 185
C		GENRAT 186
	DO 290 M=1,NMTRLS	GENRAT 187
	IN=5	GENRAT 188
	WRITE (6,69)	GENRAT 189
	CZQ(M)=4. \$ CWQ(M)=0.15	GENRAT 190
	TENS(M,1)=TENS(M,2)=-1.E11 \$ TENS(M,3)=-1.0	GENRAT 191
	YOS=0.	GENRAT 192
200	READ(IN,1090)IND,MATL(M,1),MATL(M,2),A1,RHOS(M),A2,NCMP(M),NFR(M),	GENRAT 193
	1 NPOR(M),A3,NDS(M),NPR(M),NYAM,A4,NVAR(M),A5,NCON(M)	GENRAT 194
	WRITE (6,90) IDD,MATL(M,1),MATL(M,2),A1,RHOS(M),A2,NCMP(M),NFR(M),	GENRAT 195

SUBROUTINE GENRAT (Continued)

1	NPOR(M),A3,NDS(M),NPR(M),NYAM,A4,NVAR(M),A5,NCOR(M)	GENRAT	196
2	,NIND,IND,NIN,IN,N5T	GENRAT	197
	IF (IN.EQ. 4 .OR. IND.EQ. 1DD) GO TO 205	GENRAT	198
	IN=4	GENRAT	199
	CALL REDR(MATL(M,1),MATL(M,2),IN,2)	GENRAT	200
	IF (IND.EQ. 1HT) GO TO 200	GENRAT	201
	READ(IN,1090)IND,A1,A2,A3,A4,A5,N1,N2,N3,A6,N4,N5,NYAMT,A7,A8,N6	GENRAT	202
	WRITE (6,90) 1DD,A1,A2,A3,A4,A5,N1,N2,N3,A6,N4,N5,NYAMT,A7,A8,N6,	GENRAT	203
	1 NIND,IND,NIN,IN,N5T	GENRAT	204
205	RHO(M)=RHOS(M)	GENRAT	205
	IF (NCMP(M) .NE. 0) GO TO 2055	GENRAT	206
C	**** READ IN EQST VARIABLES ****	GENRAT	207
	READ(IN,1020)A1,EQSTC(M),EQSTD(M),EQSTE(M),EQSTG(M),EQSTH(M),	GENRAT	208
1	EQSTS(M),EQSTV(M)	GENRAT	209
	WRITE (6,20) A1,EQSTC(M),EQSTD(M),EQSTE(M),EQSTG(M),EQSTH(M),	GENRAT	210
1	EQSTS(M),EQSTV(M),NIND,1DD,NIN,IN,NFT,NGT,NHT,NIT	GENRAT	211
	IF (A1.EQ. 10H EQSTX=) READ (IN,1020) A2,EQSTA(M),A3,A4,A5,A6,	GENRAT	212
1	A7,A8	GENRAT	213
	IF (A1.EQ. 10H EQSTX=) WRITE (6,20) A2,EQSTA(M),A3,A4,A5,A6,	GENRAT	214
1	A7,A8,NIND,1DD,NIN,IN	GENRAT	215
	IF (NPR(M) .LE. 1 .OR. NPR(M) .EQ. 7) CALL EQST(A1,A2,A3,M)	GENRAT	216
	LS = -1	GENRAT	217
	EMELT(M)=0.1*EQSTE(M)	GENRAT	218
	CALL FMELT(LS,M,EMELT(M),A1,A2,X,MS)	GENRAT	219
	IF (NCMP(M) .EQ. 0) GO TO 2059	GENRAT	220
C		GENRAT	221
C	**** READ COMPOSITE DATA ****	GENRAT	222
2055	CONTINUE	GENRAT	223
	LS=-1	GENRAT	224
	CALL REBAR(LS,IN,J,I,M,N,H(J,3),RHOS(M),DOLD,EXMAT(M,3),SY,SZ,	GENRAT	225
1	TXY,EH,PHL(J),EX,EY,EZ,EXY,F,O.,O.,ESC,FS,COM(1),COM(2),COM(6),	GENRAT	226
2	COM(7),YO(M),COM(8),IPRT)	GENRAT	227
	NVAR(M)=MAXO(NVAR(M),7)	GENRAT	228
	RHO(M)=RHOS(M)	GENRAT	229
	GO TO 245	GENRAT	230
2059	CONTINUE	GENRAT	231
C		GENRAT	232
C	**** READ FRACTURE DATA ****	GENRAT	233
	NFRM=NFR(M)+1	GENRAT	234
	GO TO (210,206,207,208,208,207) NFRM	GENRAT	235
206	CONTINUE	GENRAT	236
207	CONTINUE	GENRAT	237
	READ(IN,1020)A1,(TSR(M,1),1=1,7)	GENRAT	238
	WRITE (6,20) A1,(TSR(M,1),1=1,7),NIND,1DD,NIN,IN	GENRAT	239
	IF (NFR(M) .EQ. 1) GO TO 210	GENRAT	240
	IF (NFR(M) .EQ. 2) NVAR(M)=MAXO(NVAR(M),18)	GENRAT	241
	IF (NFR(M) .EQ. 5) NVAR(M)=MAXO(NVAR(M),11)	9/12/79	3
	READ(IN,1020)A1,(TSR(M,1),1=8,14)	GENRAT	243
	WRITE (6,20) A1,(TSR(M,1),1=8,14),NIND,1DD,NIN,IN	GENRAT	244
	GO TO 210	GENRAT	245
C	READ FOR SHEAR BAND MODEL.	GENRAT	246
208	CALL SHEAR2(LSUB(15),IN,M)	GENRAT	247
	NVAR(M)=MAXO(NVAR(M),5)	GENRAT	248
	LSUB(15)=1	GENRAT	249
	IF (NFR(M) .EQ. 4) GO TO 207	GENRAT	250
C		GENRAT	251
C	**** READ POROUS DATA ****	GENRAT	252
210	IF (NPOR(M) .EQ. 0) GO TO 230	GENRAT	253
	NPORM = NPOR(M)	GENRAT	254
	GO TO (211,212,225,227) NPORM	GENRAT	255
211	READ(IN,1020)A1,RHO(M)	GENRAT	256
	WRITE (6,20) A1,RHO(M)	GENRAT	257
	CALL POREQST(0,IN,M,EXMAT(M,3),RHO(M),A2,A3,A4,A5,A6,CZQ(M),CWQ(M)	GENRAT	258
1	,A7,A8,EQSTC(M),EQSTD(M),EQSTG(M),EQSTS(M),A11,A12,YO(M))	GENRAT	259
	GO TO 230	GENRAT	260
212	IF (NPOR(M) .GT. 2) GO TO 225	GENRAT	261
	CALL PORHOLT(0,IN,M,EXMAT(M,3),RHO(M),DOLD,A1,A2,A3,A4,A5,A6,A7,	GENRAT	262
1	EQSTC(M),A9,YO(M),RHOS(M),A10)	GENRAT	263
	GO TO 230	GENRAT	264
225	READ(5,1020)A1,RHO(M)	GENRAT	265
	WRITE(6,20)A1,RHO(M)	GENRAT	266
	CALL PEST(LSUB(14),5,A1,A2,A3,A4,A5,M,EXMAT(M,3),RHO(M),A6,RHOS(M)	GENRAT	267
1	,A7,A8,A9,A10,A11,A12,A13,EQSTC(M),EQSTD(M),EQSTS(M),EQSTG(M),	GENRAT	268
2	A14,YO(M),A15,A16,CZQ(M),CWQ(M),EQSTH(M),EQSTE(M),EQSTN(M),EQSTV	GENRAT	269
3	(M),EQSTA(M))	GENRAT	270

SUBROUTINE GENRAT (Continued)

	NVAR(M)=MAX0(NVAR(M),5)	GENRAT	271
	GO TO 230	GENRAT	272
227	READ(5,1021)A1,RH0(M),A2,MU(M)	GENRAT	273
	WRITE(6,21)A1,RH0(M),A2, MU(M)	GENRAT	274
	MU(M)=1.333*MU(M)	GENRAT	275
	CALL CAP1(-1,IN,M,H(1),RH0(M),RH0(M),EHL(1),0.,0.,0.,0.,1.,MU(M),	GENRAT	276
	1 EQSTC(M),EQST0(M),RH0S(M),SHL(1),SHL(1),SHL(1),SHL(1),NEM(1),	GENRAT	277
	2 K,J,NET(1))	GENRAT	278
	EXMAT(M,3)=SQRT((EQSTC(M)+MU(M))/RH0(M))	GENRAT	279
C	**** READ SPECIAL PRESSURE AND DEVIATOR STRESS DATA ****	GENRAT	280
230	IF (NDS(M) .EQ. 0) GO TO 235	GENRAT	281
	IF (NDS(M) .EQ. 7) GO TO 233	GENRAT	282
	READ(IN,1020)A1,(TSR(M,1),I=15,21)	GENRAT	283
	WRITE (6,20) A1,(TSR(M,1),I=15,21),NIND,IDD,NIN,IN	GENRAT	284
	GO TO 235	GENRAT	285
233	CALL EP(0,M)	GENRAT	286
235	IF (NPR(M) .EQ. 0) GO TO 245	GENRAT	287
	NPRM = NPR(M)	GENRAT	288
	GO TO (236,237,238,239,240,241,245) NPRM	GENRAT	289
236	CALL EXPL0DE(1,IN,M,EXMAT(M,3),A1,A2,A3,A4,A5,A6,A7,A8,A9,A10)	GENRAT	290
	GO TO 245	GENRAT	291
237	CALL ESA(0,IN,M)	GENRAT	292
	GO TO 245	GENRAT	293
238	CALL EQSTPF(0,IN,M)	GENRAT	294
	GO TO 245	GENRAT	295
239	CALL HYP0(0,IN,M,EXMAT(M,3),RH0S(M))	GENRAT	296
	GO TO 245	GENRAT	297
240	CALL GRAY(0,IN,M)	GENRAT	298
	GO TO 245	GENRAT	299
241	CALL E0STAB(0,IN,XN,YN,ZN)	GENRAT	300
	GO TO 245	GENRAT	301
C	**** READ SPALL, VISCOSITY, YIELD AND MELT VARIABLES ****	GENRAT	302
C	NYAM IS THE NUMBER OF CARDS	GENRAT	303
245	IF (NYAM .EQ. 0) GO TO 280	GENRAT	304
	DO 275 NY=1,NYAM	GENRAT	305
	READ (IN,30)(X(I),I=1,8)	GENRAT	306
	DECODE (10,24,X)(A(I),I=1,10)	GENRAT	307
	DO 250 I=1,10	GENRAT	308
	IF (A(I) .EQ. 1H) GO TO 250	GENRAT	309
	IF (A(I) .EQ. 1HT .AND. A(I+1) .EQ. 1HE) GO TO 252	GENRAT	310
	IF (A(I) .EQ. 1HC .OR. A(I) .EQ. 1HV) GO TO 253	GENRAT	311
	IF (A(I) .EQ. 1HY) GO TO 254	GENRAT	312
	IF (A(I) .EQ. 1HE .OR. A(I) .EQ. 1HM) GO TO 270	GENRAT	313
	IF (A(I) .EQ. 1HT .AND. A(I+1) .EQ. 1HH) GO TO 256	GENRAT	314
	IF (A(I) .EQ. 1HG .AND. A(I+1) .EQ. 1HM) GO TO 272	GENRAT	315
	IF (A(I) .EQ. 1HS .AND. A(I+1) .EQ. 1HP) GO TO 265	GENRAT	316
250	CONTINUE	GENRAT	317
	PRINT 67, (X(I), I=1,8)	GENRAT	318
	GO TO 398	GENRAT	319
252	DECODE(80,1020,X)A1,(TENS(M,1),I=1,3)	GENRAT	320
	WRITE (6,20) A1,(TENS(M,1),I=1,3),(T(I),I=1,4),NIND,IDD,NIN,IN,NFT	GENRAT	321
	GO TO 275	GENRAT	322
253	DECODE(80,1020,X)A1,CZQ(M),CWQ(M),C2(M)	GENRAT	323
	WRITE (6,20) A1,CZQ(M),CWQ(M),C2(M),(T(I),I=1,4),NIND,IDD,NIN,IN	GENRAT	324
	GO TO 275	GENRAT	325
254	DECODE(80,1020,X)A1,YOS,MU(M),YADD(M),EXMAT(M,1),EXMAT(M,4)	GENRAT	326
	WRITE(6,20)A1,YOS,MU(M),YADD(M),EXMAT(M,1),EXMAT(M,4),(T(I),I=1,2)	GENRAT	327
	1 ,NIND,IDD,NIN,IN,NJT,NJT,NJT	GENRAT	328
	IF (NDS(M) .NE. 5) YADD(M)=YADD(M)/(RH0S(M)*(.2-.5*YOS/MU(M)))	GENRAT	329
	IF (NPR(M) .EQ. 0) YO(M)= YOS	GENRAT	330
C	TEST FOR COULOMB FRICTION MODEL	GENRAT	331
	IF (EXMAT(M,1) .EQ. 0.) GO TO 275	GENRAT	332
C	READ IN EXMAT AS TAN(PHI), AND YOS AS 2C	GENRAT	333
	ENPHI=SQRT(1.+EXMAT(M,1)**2)+EXMAT(M,1)	GENRAT	334
	YO(M)=1.5*YOS*ENPHI/(1.+0.5*ENPHI**2)	GENRAT	335
	EXMAT(M,1)=1.5*(ENPHI**2-1.)/(1.+0.5*ENPHI**2)	GENRAT	336
	GO TO 275	GENRAT	337
265	DECODE(80,1020,X)A1,SPH(M)	GENRAT	338
	WRITE(6,20)A1,SPH(M)	GENRAT	339
	GO TO 275	GENRAT	340
270	LS = 0	GENRAT	341
	GO TO 273	GENRAT	342
272	LS= 1	GENRAT	343
273	DECODE (80,1020,X)A1,(A(I),I=1,7)	GENRAT	344
	WRITE (6,20) A1,(A(I), I=1,7),NIND,IDD,NIN,IN,NKT	GENRAT	345

SUBROUTINE GENRAT (Continued)

	IF (MS .EQ. M) GO TO 2732	GENRAT	346
	DO 2731 I=1,7	GENRAT	347
	IF (LS .EQ. 0) EMELT(M,I)=A(1)	GENRAT	348
	IF (LS .EQ. 1) GMELT(M,I)=A(1)	GENRAT	349
2731	CONTINUE	GENRAT	350
	GO TO 2733	GENRAT	351
2732	IF (LS .EQ. 0) EMELT(M,8)=A(1)	GENRAT	352
	IF (LS .EQ. 1) GMELT(M,8)=A(1)	GENRAT	353
2733	CALL FMELT(LS,M,EMELT(M),A1,A2,A,MS)	GENRAT	354
	GO TO 275	GENRAT	355
256	DECODE(80,1020,X)A1,(THERM(M,1),I=1,5)	GENRAT	356
	WRITE (6,20) A1,(THERM(M,1),I=1,7),NIND,IDD,NIN,IN,NKT	GENRAT	357
275	CONTINUE	GENRAT	358
C	**** READ IN EDGE VARIABLES	GENRAT	359
280	IF (NCON(M) .GT. 0 .AND. MATFL .EQ. 0) CALL DEPOS(1,IN)	GENRAT	360
	ESC(M,1)=RH0(M) \$ ESC(M,2)=EQSTC(M)	GENRAT	361
	ESC(M,3)=EQSTD(M) \$ ESC(M,4)=EQSTS(M)	GENRAT	362
	ESC(M,5)=MU(M) \$ ESC(M,6)=YADD(M)	GENRAT	363
	ESC(M,7)=RHOS(M) \$ ESC(M,9)=EQSTG(M)	GENRAT	364
	ESC(M,10)=YO(M)	GENRAT	365
	THERM(M,6)=EMELT(M,1)	GENRAT	366
	THERM(M,8)=EQSTE(M)	GENRAT	367
290	CONTINUE	GENRAT	368
C		GENRAT	369
C	**** END OF M-LOOP****	GENRAT	370
	WRITE (6,69)	GENRAT	371
C		GENRAT	372
C	**** READ IN ZONING VARIABLES ****	GENRAT	373
C		GENRAT	374
	DO 291 L=1,30	GENRAT	375
	JBND(L)=0	GENRAT	376
291	THK(L)=0.	GENRAT	377
	IN = 5	GENRAT	378
	READ (5,66) A1,NLAYER,A2,(JMAT(L),L=1,10)	GENRAT	379
	WRITE (6,66) A1,NLAYER,A2,(JMAT(L),L=1,10),NIND,IDD,NIN,IN	GENRAT	380
	IF (NLAYER .LE. 10) GO TO 292	GENRAT	381
	READ (5,80) (JMAT(L),L=11,NLAYER)	GENRAT	382
	WRITE (6,80) (JMAT(L),L=11,NLAYER)	GENRAT	383
292	INFF=INFL=0	GENRAT	384
	IF (JMAT(1) .LT. 0) INFF=1	GENRAT	385
	IF (JMAT(NLAYER) .LT. 0) INFL=1	GENRAT	386
	JMAT(1)=IABS(JMAT(1))	GENRAT	387
	JMAT(NLAYER)=IABS(JMAT(NLAYER))	GENRAT	388
	READ (5,30) (X(I),I=1,8)	GENRAT	389
	DECODE(4,1062,X)A1	GENRAT	390
	IF (A1 .NE. 4H THK) GO TO 293	GENRAT	391
	DECODE(80,1019,X)A1,A2,(THK(L),L=1,7)	GENRAT	392
	WRITE (6,19) A1,A2,(THK(L),L=1,7)	GENRAT	393
	IF (NLAYER .LE. 7) GO TO 2921	GENRAT	394
	READ(5,1075)(THK(L),L=8,NLAYER)	GENRAT	395
	WRITE (6,75) (THK(L),L=8,NLAYER)	GENRAT	396
2921	IF (A2 .NE. 5H INCH) GO TO 399	GENRAT	397
C		GENRAT	398
C	CONVERSION OF THK(L) FROM INCHES TO CM	GENRAT	399
	DO 2922 L=1,NLAYER	GENRAT	400
2922	THK(L)=2.54*THK(L)	GENRAT	401
	GO TO 399	GENRAT	402
293	DECODE(80,1062,X)A1,A2,NZONES(1),NCELLS(1,1),A3,A4,TH(1,1),A5,A6,	GENRAT	403
	1 DELX(1,1),A7,A8,DELFIN(1,1)	GENRAT	404
	DO 300 L=1,NLAYER	GENRAT	405
	IF (L.GT.1)READ(5,1062)A1,A2,NZONES(L),NCELLS(L,1),A3,A4,TH(L,1	GENRAT	406
	1),A5,A6,DELX(L,1),A7,A8,DELFIN(L,1)	GENRAT	407
	WRITE (6,62) A1,A2,NZONES(L),NCELLS(L,1),A3,A4,TH(L,1),A5,A6,DELX	GENRAT	408
	1 (L,1),A7,A8,DELFIN(L,1),NIND,IDD,NIN,IN,NLT	GENRAT	409
	NZON=NZONES(L)	GENRAT	410
	IF (NZON .EQ. 1) GO TO 2951	GENRAT	411
	DO 295 N1=2,NZON	9/12/79	4
	READ(5,1064)A1,A2,NCELLS(L,N1),A3,A4,TH(L,N1),A5,A6,DELX(L,N1),	9/12/79	5
	1 A7,A8,DELFIN(L,N1)	9/12/79	6
295	WRITE (6,64) A1,A2,NCELLS(L,N1),A3,A4,TH(L,N1),A5,A6,DELX(L,N1),	9/12/79	7
	1 A7,A8,DELFIN(L,N1),NIND,IDD,NIN,IN,NLT	9/12/79	8
2951	IF (A5 .NE. 5H INCH) GO TO 300	GENRAT	417
C		GENRAT	418
C	CONVERSION OF TH(L,N), DELX(L,N) FROM INCHES TO CM	GENRAT	419
	DO 2952 N1=1,NZON	9/12/79	9

SUBROUTINE GENRAT (Continued)

	TH(L,N1)=2.54*TH(L,N1)	9/12/79	10
2952	DELX(L,N1)=2.54*DELX(L,N1)	9/12/79	11
300	CONTINUE	GENRAT	423
C		GENRAT	424
C	**** CALCULATE ZONING AND INITIALIZE CELL COORDINATES ****	GENRAT	425
	NULL=0 \$ XZERO=0. \$ J=1 \$ X(1)=0.	GENRAT	426
	DO 390 L=1,NLAYER	GENRAT	427
	IF (JMAT(L) .EQ. 0) GO TO 385	GENRAT	428
	NZON=NZONES(L)	GENRAT	429
	DO 380 NZ=1,NZON	GENRAT	430
	FN=NCELLS(L,NZ) \$ RATIO=1. \$ FI=0. \$ DX=DELX(L,NZ)	GENRAT	431
	IF (DX*DELFIN(L,NZ) .EQ. 0.) GO TO 345	GENRAT	432
C	PREPARE FOR GEOMETRIC PROGRESSION OF CELLS	GENRAT	433
	RATIO=DELFIN(L,NZ)	GENRAT	434
	DX=(1.-RATIO)/(1.-RATIO**FN)*TH(L,NZ) \$ GO TO 360	GENRAT	435
C	PREPARE FOR ARITHMETIC PROGRESSION OF CELLS	GENRAT	436
345	IF (DX .NE. 0.) GO TO 355	GENRAT	437
	IF (DELFIN(L,NZ) .NE. 0.) GO TO 350	GENRAT	438
	DX=TH(L,NZ)/FN \$ GO TO 360	GENRAT	439
350	DX=2.*TH(L,NZ)/FN-DELFIN(L,NZ)	GENRAT	440
355	FI=2.*(TH(L,NZ)/FN-DX)/(FN-1.)	GENRAT	441
360	JN=J+NCELLS(L,NZ) \$ J1=J+1	GENRAT	442
	DO 365 I=J1,JN	GENRAT	443
	X(I)=X(I-1)+DX	GENRAT	444
	XO(I)=X(I)	GENRAT	445
365	DX=RATIO*DX+FI	GENRAT	446
380	J=JN \$ JBND(L)=J \$ J=J+1	GENRAT	447
	XZERO=X(J)=X(J-1)	GENRAT	448
	XO(J)=X(J)	GENRAT	449
	GO TO 390	GENRAT	450
385	XZERO=X(J)=XZERO+TH(L,1)	GENRAT	451
	NULL=NULL+1	GENRAT	452
390	CONTINUE	GENRAT	453
	JINIT=1 \$ JFIN=J	GENRAT	454
C	**** RESET JBND'S IF SOME LAYERS ARE VACANT.	GENRAT	455
	NULL=0.	GENRAT	456
	DO 395 L=1,NLAYER	GENRAT	457
	IF (JMAT(L) .EQ. 0) GO TO 393	GENRAT	458
	JBND(L-NULL)=JBND(L)	GENRAT	459
	JMAT(L-NULL)=JMAT(L)	GENRAT	460
	GO TO 395	GENRAT	461
393	NULL=NULL+1	GENRAT	462
395	CONTINUE	GENRAT	463
	NLAYER=NLAYER-NULL	GENRAT	464
396	IF (JFIN .LE. 201) GO TO 399	GENRAT	465
	WRITE (6,96) JFIN	GENRAT	466
398	READ(5,30) (A(I), I=1,8)	GENRAT	467
	PRINT 30, (A(I), I=1,8)	GENRAT	468
	IF (EOF(5)) 100,398	GENRAT	469
C		GENRAT	470
C	**** READ RADIATION SOURCE DATA ****	GENRAT	471
399	IF (MATFL .EQ. 0) CALL DEPOS(2,IN)	GENRAT	472
C		GENRAT	473
C	**** INITIALIZE THE J-ARRAY VARIABLES ****	GENRAT	474
C		GENRAT	475
	DO 601 I=1,2400	GENRAT	476
601	CHL(I)=0.	GENRAT	477
	J1=1	GENRAT	478
	LVMAX=1	GENRAT	479
	DO 630 L=1,NLAYER	GENRAT	480
	M=JMAT(L)	GENRAT	481
	YOM=YO(M)	GENRAT	482
	IF (NPOR(M) .NE. 0) GO TO 602	GENRAT	483
	IF (NPR(M) .EQ. 4) GO TO 602	GENRAT	484
	DET=EXMAT(M,3)	GENRAT	485
	CJ=AMAX1(DET,SQRT((EQSTC(M)+1.333*MU(M))/RHOS(M)),5.E4)	GENRAT	486
	HH=SOLID \$ GO TO 603	GENRAT	487
602	HH=POROUS \$ CJ=EXMAT(M,3)	GENRAT	488
	IF (RHO(M) .EQ. RHOS(M)) HH = SOLID	GENRAT	489
603	JN=JBND(L)	GENRAT	490
	DO 610 J=J1,JN	GENRAT	491
	CHL(J)=CJ	GENRAT	492
	DHL(J)=RHO(M)	GENRAT	493
	H(J,1)=HH	GENRAT	494
	IF (NPR(M) .EQ. 1) CALL EXPLODE(2,IN,M,EHL,DHL,DOLD,PHL,SHL,NEM,X,	GENRAT	495

SUBROUTINE GENRAT (Continued)

1	J,A1,A2,A3)	GENRAT	496
	IF (NVAR(M) .LE. 0) GO TO 604	GENRAT	497
	LVAR(J)=LVMAX	GENRAT	498
	LVMAX=LVMAX+NVAR(M)	GENRAT	499
604	CONTINUE	GENRAT	500
	IF (NPOR(M) .EQ. 3) COM(LVMAX+3)=1.-RHO(M)/RHOS(M)	GENRAT	501
	IF (J .NE. J1) H(J,2)=NORMAL	GENRAT	502
	H(J,3)=2	GENRAT	503
	T(J)=TENS(M,1)	GENRAT	504
	YHL(J)=YOM	GENRAT	505
	ZHL(J)=DHL(J)*(X(J+1)**NALPHA-X(J)**NALPHA)	GENRAT	506
	NDSM1=NDS(M)+1	GENRAT	507
	GO TO (610,610,605,606,610,607,605,610) NDSM1	GENRAT	508
605	NEM(J)=TSR(M,21) \$ GO TO 610	GENRAT	509
606	NEM(J)=TSR(M,19) \$ GO TO 610	GENRAT	510
607	NEM(J)=YHL(J)	GENRAT	511
610	CONTINUE	GENRAT	512
	H(J1,2)=RINTER	GENRAT	513
	IF (J1 .EQ. 1) GO TO 620	GENRAT	514
	IF (X(J1) .GT. X(J1-1)) H(J1,2)=SPALL	GENRAT	515
620	CONTINUE	GENRAT	516
	T(JN)=TENS(M,3)	GENRAT	517
	H(JN,2)=LINTER	GENRAT	518
	J1=JN+1	GENRAT	519
630	CONTINUE	GENRAT	520
	ZHL(JFIN-1)=0.	GENRAT	521
	H(1,2)=H(JFIN,2)=SPALL	GENRAT	522
	IF (INFF .EQ. 1) H(1,2)=INF	GENRAT	523
	IF (INFL .EQ. 1) H(JFIN,2)=INF	GENRAT	524
	IF (INFF .EQ. 1) ZHL(INFF-1)=ZHL(1)	GENRAT	525
C	TO ACTIVATE THIS ROUTINE, DTMAX IS NEGATIVE OF NUMBER OF CELLS	GENRAT	526
C	DESIRED IN LAYER NUMBER(-NREZON)	GENRAT	527
	IF (DTMAX .GT. 0. .OR. NREZON .GE.0) GO TO 635	GENRAT	528
	JB=JBND(-NREZON)	GENRAT	529
	X1=0.	GENRAT	530
	IF (NREZON .EQ. -1) GO TO 632	GENRAT	531
	JB1=JBND(-NREZON-1)	GENRAT	532
	X1=X(JB1)	GENRAT	533
632	DTMAX=-(X(JB)-X1)/(CHL(JB-1)*DTMAX)	GENRAT	534
	NREZON=-30	GENRAT	535
635	CONTINUE	GENRAT	536
	DTNH=1.E-12	GENRAT	537
C	CHECK FOR END OF DATA DECK AND CALL FOR ADDED READS	GENRAT	538
C	INSERT CARD HERE READING EXTRA	GENRAT	539
638	READ 30,A1	GENRAT	540
	IF (EOF(5)) 650,640	GENRAT	541
640	IF (A1 .EQ. 10H H-DATA) GO TO 642	GENRAT	542
	IF (A1 .EQ. 10H EXTRA) GO TO 645	GENRAT	543
	GO TO 398	GENRAT	544
642	CALL HDATA(H)	GENRAT	545
	GO TO 638	GENRAT	546
645	CALL EXTRA	GENRAT	547
650	CONTINUE	GENRAT	548
	IF (MATFL) 815,700,800	GENRAT	549
C*****	DEPOSITION EDIT	GENRAT	550
700	CALL DEPOS(3,IN)	GENRAT	551
	GO TO 900	GENRAT	552
C	INITIALIZE VELOCITY	GENRAT	553
800	JFIN2=JBND(MATFL)	GENRAT	554
	IF (UZERO.EQ.0.) JFIN2=2	GENRAT	555
	DO 810 J=1,JFIN2	GENRAT	556
810	U(J)=UZERO	GENRAT	557
	DTNH=0.02*AMIN1((X(JFIN2)-X(JFIN2-1))/CHL(JFIN2-1),(X(JFIN2+2)-	GENRAT	558
1	X(JFIN2+1))/CHL(JFIN2+1))	GENRAT	559
	JSTAR=JFIN2+3 \$ SDURM=1. \$ GO TO 818	GENRAT	560
815	IF (MATFL+2) 817,816,8151	GENRAT	561
8151	H(1,2)=MIRROR \$ JSTAR=3 \$ SDURM=1. \$ U(1)=0.5*UZERO	GENRAT	562
	GO TO 818	GENRAT	563
816	JSTAR=3 \$ SDURM=1. \$ H(1,2)=PRESS	GENRAT	564
	GO TO 818	GENRAT	565
817	JSTAR=JFIN \$ SDURM=1. \$ H(JFIN,2)=PRESS	GENRAT	566
C		GENRAT	567
C*****	VELOCITY EDIT	GENRAT	568
818	IF (H(1,2) .EQ. SPALL) GO TO 819	GENRAT	569
	A2=5HFRONT	GENRAT	570

SUBROUTINE GENRAT (Concluded)

	A1=10H UNKNOWN	GENRAT	571
	IF (H(1,2) .EQ. MIRROR) A1=10H MIRROR	GENRAT	572
	IF (H(1,2) .EQ. INF) A1=10H INFINITE	GENRAT	573
	IF (H(1,2) .EQ. PRESS) A1=10H PRESSURE	GENRAT	574
	IF(INFF .EQ. 1) U(JFIN+1)=U(1)	GENRAT	575
	PRINT 50,A1,A2	GENRAT	576
819	IF (H(JFIN,2) .EQ. SPALL) GO TO 8195	GENRAT	577
	A2=5HREAR \$ A1=10H UNKNOWN	GENRAT	578
	IF(H(JFIN,2) .EQ. INF) A1=10H INFINITE	GENRAT	579
	IF(H(JFIN,2) .EQ. PRESS) A1=10H PRESSURE	GENRAT	580
	PRINT 50,A1,A2	GENRAT	581
8195	WRITE (6,16) (DISCPT(I),I=1,10)	GENRAT	582
	IF (EHL(J) .GT. 1.) JSTAR=MAXO(JSTAR,J)	GENRAT	583
	DO 820 J=1,JFIN	GENRAT	584
820	A(J)=X(J+1)-X(J)	GENRAT	585
	L=K=J1=1	GENRAT	586
825	J2=MINO(JFIN-1,50*K,JBND(L))	GENRAT	587
	M=JMAT(L)	GENRAT	588
	WRITE (6,17) (J,A(J),X(J),U(J),YHL(J),CHL(J),DHL(J),T(J),ZHL(J),	GENRAT	589
	1 EHL(J),MATL(M,1),(H(J,I),I=1,3),J,J=J1,J2)	GENRAT	590
	IF (J2 .EQ. JFIN-1) GO TO 900	GENRAT	591
	J1=J2+1	GENRAT	592
	IF (J2 .NE. 50*K) GO TO 830	GENRAT	593
	K=K+1 \$ WRITE (6,16) (DISCPT(I),I=1,10)	GENRAT	594
830	IF (J2 .NE. JBND(L)) GO TO 825	GENRAT	595
	L=L+1 \$ WRITE (6,69) \$ GO TO 825	GENRAT	596
900	CALL SECOND(TWIX) \$ DUR=TWIX-FIRST	GENRAT	597
	WRITE (6,18) DUR	GENRAT	598
	WRITE (6,41)	GENRAT	599
	IF (JCYCS .LE. 0 .OR. LSUB(7) .EQ. 1) GO TO 100	GENRAT	600
C	**** PREPARE FOR STORAGE OF HISTORIES ****	GENRAT	601
	IF (NJEDIT .GE. 1) CALL PRESER	GENRAT	602
C		GENRAT	603
	RETURN	GENRAT	604
	END	GENRAT	605

SUBROUTINE GRAY

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SUBROUTINE GRAY(NPART,IN,M,AMU,EMELT,D,E,CH,P,DPDD,DPDE,IH)      GRAY  2
C                                                                    GRAY  3
C    GRAY 3-PHASE EOS OF ROYCE AT LLL. REF UCRL-51121             GRAY  4
C    MODIFIED IN THE LIQUID-VAPOR REGION BY YOUNG AT LLL.         GRAY  5
C    REF. UCRL-51575                                              GRAY  6
C                                                                    GRAY  7
C    DIMENSION A(10),ALFLS(10),AYBLS(10),C(10),CE2(10),CTA2(10), GRAY  8
1   CTB1(10),CTB2(10),C1LS(10),C2LS(10),C3LS(10),DSLS(10),D1LS(10), GRAY  9
2   D2LS(10),D3LS(10),E00(10),GO(10),GPLS(10),PCCLS(10),RPLS(10), GRAY 10
3   S(10),TH(10),TMO(10),VB(10),VO(10),XJ(10),ZJ(10)           GRAY 11
C    DIMENSION TEMP(50,10),PRES(50,10),VMN(50,10),VMX(50,10),EMN(50,10) GRAY 12
1   ,EMX(50,10),JMX(10)                                          GRAY 13
C    IF (NPART.GT. 0) GO TO 40                                     GRAY 14
C                                                                    GRAY 15
C    **** READ DATA AND PRINT                                     GRAY 16
C                                                                    GRAY 17
C    READ 1000,A1,A(M),ALFLS(M),AYBLS(M),C(M),CE2(M),CTA2(M),CTB1(M), GRAY 17
1   A2,CTB2(M),C1LS(M),C2LS(M),C3LS(M),DSLS(M),D1LS(M),D2LS(M), GRAY 18
2   A3,D3LS(M),E00(M),GO(M),GPLS(M),PCCLS(M),RPLS(M),S(M), GRAY 19
3   A4,TH(M),TMO(M),VB(M),VO(M),XJ(M),ZJ(M)                   GRAY 20
C    PRINT 1000,A1,A(M),ALFLS(M),AYBLS(M),C(M),CE2(M),CTA2(M),CTB1(M), GRAY 21
1   A2,CTB2(M),C1LS(M),C2LS(M),C3LS(M),DSLS(M),D1LS(M),D2LS(M), GRAY 22
2   A3,D3LS(M),E00(M),GO(M),GPLS(M),PCCLS(M),RPLS(M),S(M), GRAY 23
3   A4,TH(M),TMO(M),VB(M),VO(M),XJ(M),ZJ(M)                   GRAY 24
1000 FORMAT(A10,1P7E10.3)                                       GRAY 25
C    READ 1001,A1,JMX(M)                                          GRAY 26
C    PRINT 1001,A1,JMX(M)                                         GRAY 27
1001 FORMAT(A10,I10)                                             GRAY 28
C    IMAX=JMX(M)                                                  GRAY 29
C    DO 30 I=1,IMAX                                              GRAY 30
C    READ 1000,A1,TEMP(I,M),VMX(I,M),VMN(I,M),EMX(I,M),EMN(I,M),PRES(I, GRAY 31
1   M)                                                            GRAY 32
C    PRINT 1000,A1,TEMP(I,M),VMX(I,M),VMN(I,M),EMX(I,M),EMN(I,M),PRES(I, GRAY 33
1   M)                                                            GRAY 34
30  CONTINUE                                                     GRAY 35
C    RETURN                                                       GRAY 36
C                                                                    GRAY 37
C    **** COMPUTE PRESSURE, SOUND SPEED, (DP/DD)E, AND (DP/DE)V GRAY 38
40  D1=D                                                         GRAY 39
C    E1=E                                                         GRAY 40
C    NLOOP=0                                                      GRAY 41
50  NLOOP=NLOOP+1                                                GRAY 42
C    IF (NLOOP-2) 100,55,60                                       GRAY 43
55  PR1=P                                                         GRAY 44
C    D2=D=D1+.001*D1                                              GRAY 45
C    GO TO 100                                                      GRAY 46
60  PR2=P                                                         GRAY 47
C    D=D1                                                           GRAY 48
C    E=E3=E+.001*E+1.E5                                           GRAY 49
100 X=(VO(M)-1./D)/VO(M)                                         GRAY 50
C    V=1./D                                                         GRAY 51
C    IF (V.LE. 1.04*VO(M)) GO TO 145                              GRAY 52
C    EN=EMX(2,M)                                                   GRAY 53
C    IF (E.GE. 1.2*EN) GO TO 140                                   GRAY 54
C                                                                    GRAY 55
C    USE CRITICAL POINT AND TIE LINES TO REPLACE VAN DER WAALS LOOPS IN GRAY 56
C    LIQUID-VAPOR PHASE.                                          GRAY 57
C                                                                    GRAY 58
C    VX=M1=VMM1=VMN(1,M)                                           GRAY 59
C    EX=M1=EMM1=EMN(1,M)                                           GRAY 60
C    EQM=EMM1+(EN-EMN(2,M))*(V-VMM1)/(VMX(2,M)-VMN(2,M))        GRAY 61
C    JMAX=JMX(M)                                                   GRAY 62
C    DO 110 J=2,JMAX                                               GRAY 63
C    VX=VMX(J,M)                                                   GRAY 64
C    EX=EMX(J,M)                                                   GRAY 65
C    VN=VMN(J,M)                                                   GRAY 66
C    EN=EMN(J,M)                                                   GRAY 67
C    EQ=EN+(EX-EN)*(V-VN)/(VX-VN)                                  GRAY 68

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SUBROUTINE GRAY (Continued)

	IF (E .LT. EQ) GO TO 105	GRAY 69
	EH=EN+(EMM1-EN)*(V-VN)/(VMM1-VN)	GRAY 70
	IF (E .GE. EH) GO TO 140	GRAY 71
	EL=EX+(EX-EXM1)*(V-VX)/(VX-VXM1)	GRAY 72
	IF (E-EL) 115,140,140	GRAY 73
105	EQM=EQ	GRAY 74
	VXM1=VX	GRAY 75
	VMM1=VN	GRAY 76
	EXM1=EX	GRAY 77
	EMM1=EN	GRAY 78
110	CONTINUE	GRAY 79
	J=JMAX	GRAY 80
	EL=EX*VX/V	GRAY 81
	IF (E .GE. EL) GO TO 140	GRAY 82
	SL=-EN/(.96/VO(M)-1.0/VN)	GRAY 83
	EH=EN+SL*(1.0/V-1.0/VN)	GRAY 84
	IF (E .GE. EH) GO TO 145	GRAY 85
	TM1=TEMP(J-1,M)	GRAY 86
	TM=TEMP(J,M)	GRAY 87
	T=(E/EQM)*(TM-300.)*300.	GRAY 88
	NAME=10H LIQ-VAPOR	GRAY 89
	GO TO 120	GRAY 90
115	NAME=10H LIQ-VAPOR	GRAY 91
	ER=(EQM-E)/(E-EQ)	GRAY 92
	TM=TEMP(J,M)	GRAY 93
	TM1=TEMP(J-1,M)	GRAY 94
	T=(TM*ER+TM1)/(1.+ER)	GRAY 95
120	PQ=PRES(J)	GRAY 96
	SLP=ALOG(PRES(J-1,M)/PQ)/(1./TM1-1./TM)	GRAY 97
	P=PQ*EXP(SLP*(1.0/T-1.0/TM))	GRAY 98
	IH=5R 0	GRAY 99
	GO TO 700	GRAY 100
C	BRANCH TO VAPOR LIQUID STATE (6)	GRAY 101
140	IF (X .LT. XJ(M)) GO TO 600	GRAY 102
C	START COMPUTATIONS FOR SOLID-LIQUID STATES (5)	GRAY 103
145	EO=(C(M)*X)**2/2./(1.-S(M)*X)*(1.+S(M)*X/3.+CE2(M)*X*X)	GRAY 104
	1 +EOO(M)*(1+GO(M)*X)	GRAY 105
	G=GO(M)-A(M)*X	GRAY 106
	P1=(C(M)/(1.-S(M)*X))**2*X*D*(1.-X-0.5*G*X) +G*E*D	GRAY 107
	IF (X .GE. 0.) GO TO 150	GRAY 108
	TM=TMO(M)/(1.-X)**2*(1.+(CTB1(M)-2.)*X+CTA2(M)*X*X)	GRAY 109
	GO TO 155	GRAY 110
150	TM=TMO(M)*(1.+CTB1(M)*X+CTB2(M)*X*X)	GRAY 111
155	CONTINUE	GRAY 112
	DT=DSLS(M)*((CTB1(M)-A(M)*X)*TM/C(M))**2/(2.4*(1.-X)*(1.+	GRAY 113
	1 AMAX1(0.,(4*S(M)-1.)*X))	GRAY 114
	TMDT=TM-DT	GRAY 115
	EM1=EO+TMDT*(3.*RPLS(M)+0.5*GPLS(M)*TMDT)	GRAY 116
C	BRANCH POINT	GRAY 117
	IF (E .GT. EM1) GO TO 300	GRAY 118
C		GRAY 119
C	**** SOLID EQUATION OF STATE ****	GRAY 120
200	QUAD=9.*RPLS(M)**2+2.*GPLS(M)*(E-EO)	GRAY 121
	IF (QUAD .LT. 0.) GO TO 800	GRAY 122
	T=(-3.*RPLS(M)+SQRT(QUAD))/GPLS(M)	GRAY 123
	PC=(0.666667-G)*GPLS(M)*T**2*D/2.	GRAY 124
	P=P1+PC+PCCLS(M)	GRAY 125
	IH=5R S	GRAY 126
	GO TO 700	GRAY 127
300	TMDT=TM+DT	GRAY 128
	EM2=EO+TM*(DSLS(M)-0.5*ALFLS(M)) + TMDT*(3.*RPLS(M)+0.5*TMDT*	GRAY 129
	1 (GPLS(M)-ALFLS(M)/TM))	GRAY 130
	ALAMB =-CTB1(M)+2.*A(M)*X	GRAY 131
C	BRANCH POINT	GRAY 132
	IF (E .GT. EM2) GO TO 400	GRAY 133
C		GRAY 134

SUBROUTINE GRAY (Concluded)

C	**** MELT EQUATION OF STATE	**** GRAY 135
	ENU=(E-EM1)/(EM2-EM1)	GRAY 136
	ENUSA=ENU*(DSLS(M)-ALFLS(M))	GRAY 137
	RNU=3.*RPLS(M)+ENUSA	GRAY 138
	QUAD=RNU**2+2.*GPLS(M)*(E-E0+ENU*DT*ENUSA)	GRAY 139
	IF (QUAD .LT. 0.) GO TO 800	GRAY 140
	T=(-RNU+SQRT(QUAD))/GPLS(M)	GRAY 141
	PC=D*(0.5*(0.666667-G)*GPLS(M)*T-T-ENUSA*(ALAMB*TM+G*(T-ENU*DT)))	GRAY 142
	P=P1+PC+PCCLS(M)	GRAY 143
	IH=6R M	GRAY 144
	GO TO 700	GRAY 145
400	EGG=E0+TM*(28.78*RPLS(M)+DSLS(M)+46.017*GPLS(M)*TM-46.517*ALFLS(M))	GRAY 146
1	)	GRAY 147
C	BRANCH POINT	GRAY 148
	IF (E .GT. EGG) GO TO 500	GRAY 149
C	**** LIQUID EQUATION OF STATE	GRAY 150
C	GAT=GPLS(M)-ALFLS(M)/TM	GRAY 151
	QUAD=9.*RPLS(M)**2+2.*GAT*(E-E0-TM*(DSLS(M)-0.5*ALFLS(M)))	GRAY 152
	IF (QUAD .LT. 0.) GO TO 800	GRAY 154
	T=(-3.*RPLS(M)+SQRT(QUAD))/GAT	GRAY 155
	PC=D*(0.5*(0.666667-G)*GPLS(M)*T**2-TM*(DSLS(M)-0.5*ALFLS(M)*	GRAY 156
1	(1.+(T/TM)**2))*(ALAMB+G))	GRAY 157
	P=P1+PC+PCCLS(M)	GRAY 158
	IH=6R L	GRAY 159
	GO TO 700	GRAY 160
C		GRAY 161
C	**** HOT LIQUID EQUATION OF STATE	GRAY 162
500	QUAD=(3.*RPLS(M)-9.5934*ALFLS(M))**2+2.*GPLS(M)*(E-E0-TM*(DSLS(M)	GRAY 163
1	+45.517*ALFLS(M)))	GRAY 164
	IF (QUAD .LT. 0.) GO TO 800	GRAY 165
	T=(-(3.*RPLS(M)-9.5934*ALFLS(M))+SQRT(QUAD))/GPLS(M)	GRAY 166
	PC=D*(0.5*(0.666667-G)*GPLS(M)*T-T-TM*(DSLS(M)+ALFLS(M)*(45.517	GRAY 167
1	-9.5934*T/TM)))*(ALAMB+G)	GRAY 168
	P=P1+PC+PCCLS(M)	GRAY 169
	IH=6R H	GRAY 170
	GO TO 700	GRAY 171
C		GRAY 172
C	**** LIQUID-VAPOR EQUATION OF STATE	GRAY 173
600	Z=D*VB(M)	GRAY 174
	FE=0.5*VB(M)*(((TH(M)-ZJ(M))/(TH(M)-Z))**2*(2.*Z-2.+TH(M))	GRAY 175
1	-(2.*ZJ(M)-2.+TH(M)))*(TH(M)-ZJ(M))/ZJ(M)**3	GRAY 176
	QUAD=(3.*RPLS(M)+2.*D2LS(M))**2-16.*(E+AYBLS(M)*Z-C1LS(M)*FE	GRAY 177
1	-D1LS(M))*(C3LS(M)*FE-D3LS(M))	GRAY 178
	IF (QUAD .LT. 0.) GO TO 800	GRAY 179
	T=(3.*RPLS(M)+2.*D2LS(M)-SQRT(QUAD))/4./(C3LS(M)*FE-D3LS(M))	GRAY 180
	FP=(Z*(TH(M)-ZJ(M))/ZJ(M)/(TH(M)-Z))**3	GRAY 181
	P=RPLS(M)*T/VB(M)*Z*(1.+Z*(1.+Z*(1.-Z)))/(1.-Z)**3-AYBLS(M)/VB(M)	GRAY 182
1	*Z*Z +FP*(C1LS(M)+T*(C2LS(M)+C3LS(M)*T))	GRAY 183
	IH=6R V	GRAY 184
700	IF (NLOOP .LT. 3 .AND. CH .NE. 1.) GO TO 50	GRAY 185
	PR3=P	GRAY 186
	DPDD=(PR2-PR1)/(D2-D1)	GRAY 187
	DPDE=(PR3-PR1)/(E3-E1)	GRAY 188
	CH2=DPDD+P1*DPDE/D1**2+1.333*AMU/D1	GRAY 189
	IF (CH2 .GT. 0.) CH=SQRT(CH2)	GRAY 190
	E=E1	GRAY 191
	D=D1	GRAY 192
	IF (E .GT. EMELT) P=AMAX1(P,0.)	GRAY 193
	RETURN	GRAY 194
800	CONTINUE	GRAY 195
	IH=6R Z	GRAY 196
	P=0.	GRAY 197
	RETURN	GRAY 198
	END	GRAY 199

SUBROUTINE HAFSTEP

	SUBROUTINE HAFSTEP	HAFSTEP	2
C		HAFSTEP	3
C	* CALLED BY HYDRO TO COMPUTE X, U, D, E FOR THE	HAFSTEP	4
C	* HALFSTEP POINT BETWEEN J AND J+1	HAFSTEP	5
C	INPUT - J, M.	HAFSTEP	6
C	OUTPUT - UHL, DHL, EHL.	HAFSTEP	7
C		HAFSTEP	8
	INTEGER H, POROUS, PRESS, RINTER, SOLID, SPALL	PUFCOM	2
	REAL MATL, NEM, NET, NEMH, NETH	PUFCOM	3
C	MISCELLANEOUS	PUFCOM	4
	COMMON AZERO(1), CEF, CKS, DAVG, DELTIM, DISCPT(10), DOLD, DRHO, DTMAX,	PUFCOM	5
1	DTMIN, DTN, DTNH, DU, DX, EOLD, F, FAC, FIRST, J, JCYS, JINIT,	PUFCOM	6
2	JFIN, JREZON(15), JSMAX, JSTAR, JTS, LSUB(30), M, MAXPR(30), N, NCYCS,	PUFCOM	7
3	NEDIT, NPERN, NR, NREZON, NSCRB(6), NSEPRAT, NSPALL, NTEDT,	PUFCOM	8
4	NTEX, NTR(15), POLD, P6(20), R(30), RLAST, SLAST, SMAX, TEDIT(50),	PUFCOM	9
5	TF, TIME, TJ, TREZON, TS, T6(20), ULAST, UOLD, UZERO, XLAST, XNOW, XOLD	PUFCOM	10
1	, XJDIT(20), MS	PUFCOM	11
C	HALFSTEP VALUES	PUFCOM	12
	COMMON DH, DHLAST, DUH, EH, PH, RH, RHLAST, SH, SHLAST, UH, UHLAST, XH, XHLAST	PUFCOM	13
1	, NEMH, NETH	PUFCOM	14
C	CONDITION INDICATORS	PUFCOM	15
	COMMON INF, LINTER, MIRROR, NORMAL, POROUS, PRESS, RINTER, SOLID, SPALL	PUFCOM	16
C	CELL LAYOUT	PUFCOM	17
	COMMON DXX(30), JBND(30), JMAT(30), NAUTO, MATL(6,2), NLAYER, NMTRLS,	PUFCOM	18
1	THK(30)	PUFCOM	19
C		PUFCOM	20
C	COORDINATE ARRAYS	COORDCOM	2
	COMMON/COORD/X(200), XO(200), CHL(200), DHL(200), DPDD(200), DPDE(200),	COORDCOM	3
1	EHL(200), H(200,3), NEM(200), NET(200), PHL(200), RHL(200), SDT(200),	COORDCOM	4
2	SHL(200), T(200), U(200), YHL(200), ZHL(200)	COORDCOM	5
C	NAMED COMMON	EQSTCOM	2
	REAL MU, MUM	EQSTCOM	3
	COMMON /EQS/ EQSTA(6), EQSTC(6), EQSTD(6), EQSTE(6), EQSTG(6),	EQSTCOM	4
1	EQSTH(6), EQSTN(6), EQSTS(6), EQSTV(6), CZQ(6), CWQ(6), C2(6)	EQSTCOM	5
	COMMON /MELT/ EMELT(6,8), OMELT(6,8), SPH(6), THERM(6,8)	EQSTCOM	6
	COMMON /RHO/ RHO(6), RHOS(6)	EQSTCOM	7
	COMMON /TSR/ TSR(6,30), EXMAT(6,20), TENS(6,3)	EQSTCOM	8
	COMMON /Y/ YO(6), YADD(6), MU(6), MUM, YADDM	EQSTCOM	9
	COMMON /IND/ IEOS(6), INDK(20), NALPHA, NCMP(6), NFR(6), NPOR(6),	INDCOM	2
1	NDS(6), NPR(6), NCON(6), NVAR(6)	INDCOM	3
	COMMON /RAD/ SSTOP(9), START(9), SDURM, SSTOPM, NSPEC, SSJ, JSS, IPLDT(4)	RADCOM	2
1	, XMAX(4), XMIN(4), YMAX(4), YMIN(4), IA(7), ITITLE(24), NARZ, TARZ	RADCOM	3
C		HAFSTEP	14
C		HAFSTEP	15
	DX=X(J+1)-X(J) \$ EOLD=EHL(J)	HAFSTEP	16
	DOLD=DHL(J)	HAFSTEP	17
	IF (NALPHA .GT. 1) GO TO 20	HAFSTEP	18
	DHL(J) = DH = DHEND = ZHL(J)/(DX+0.5*DTNH*(U(J+1)-U(J)))	HAFSTEP	19
	GO TO 25	HAFSTEP	20
20	DHL(J)=DH=DHEND=ZHL(J)/((X(J+1)+0.5*DTNH*U(J+1))*NALPHA-(X(J)+	HAFSTEP	21
1	0.5*DTNH*U(J))*NALPHA)	HAFSTEP	22
25	IF (NPR(M) .EQ. 7) GO TO 200	HAFSTEP	23
	NSC=MAX1(1., 100.*ABS((DHEND-DOLD))/(DHEND+DOLD))	HAFSTEP	24
	NSC=MIN0(NSC, 10)	HAFSTEP	25
	DDH = (DHEND-DOLD)/NSC	HAFSTEP	26
	SSC=0. \$ IF (NSPEC .NE. 0 .AND. SDURM .LT. 1.) SSC=SSCALH(J)/NSC	HAFSTEP	27
	IF (NSC .EQ. 1) GO TO 50	HAFSTEP	28
	PRINT 1030, NSC, J, N	HAFSTEP	29
1030	FORMAT (* SUBCYCLING IN HAFSTEP, NSC=*13, * FOR J=*13, *, N=*15)	HAFSTEP	30
	DTNS = DTN	HAFSTEP	31
	DTNHS = DTNH	HAFSTEP	32
	DTNH = DTNH/NSC	HAFSTEP	33
50	DO 120 NS = 1, NSC	HAFSTEP	34
	DHL(J) = DH = DOLD+DDH	HAFSTEP	35
	HDV=0.5*(1./DOLD-1./DH)	HAFSTEP	36
	RHOLD=SHL(J)+FAC*(RHL(J)-SHL(J))	HAFSTEP	37
	EH=EOLD+HDV*FAC*(2.*RHOLD+DPDD(J)*(DH-DOLD)+DPDE(J)*SSC)+SSC	HAFSTEP	38
	IF (NALPHA-2) 70, 60, 65	HAFSTEP	39
C	CYLINDRICAL CASE	HAFSTEP	40
60	EZ=(SHL(J)-PHL(J)-SDT(J))*(-2.*HDV-(U(J+1)-U(J))*(DTNH+DTN)/	HAFSTEP	41
1	(X(J+1)-X(J))/(DH+DOLD))	HAFSTEP	42
	EH=EH+EZ \$ GO TO 70	HAFSTEP	43
C	SPHERICAL CASE	HAFSTEP	44
65	EZ=1.5*(SHL(J)-PHL(J))*(2.*HDV-(U(J+1)-U(J))*(DTNH+DTN)/(X(J+1)-	HAFSTEP	45
1	X(J))/(DH+DOLD))	HAFSTEP	46

SUBROUTINE HAFSTEP (Concluded)

	EH=EH+EZ	HAFSTEP	47
70	CONTINUE	HAFSTEP	48
C	CALL HSTRESS TO COMPUTE STRESS VARIABLES	HAFSTEP	49
	CALL HSTRESS	HAFSTEP	50
	RHL(J)=RH	HAFSTEP	51
	EHL(J) = EH	HAFSTEP	52
	IF (NPR(M) .EQ. 1 .OR. NPR(M) .EQ. 4) GO TO 90	HAFSTEP	53
	RHL(J)=RH=(RH+DPDE(J)*(EOLD+SSC-EH+FAC*HDV*RHOLD))/(1.-HDV*DPDE(J)	HAFSTEP	54
	1 *FAC)	HAFSTEP	55
	EHL(J)=EH=(RHOLD+SHL(J)+FAC*(RH-SHL(J)))*HDV+EOLD+SSC	HAFSTEP	56
	IF (NALPHA .GT. 1) EHL(J)=EH+EZ	HAFSTEP	57
	IF (NPR(M) .NE. 3) GO TO 90	HAFSTEP	58
	DPDDA=EQSTG(M)*EH+EQSTC(M)/RH0(M)	HAFSTEP	59
	IF (DH .EQ. DOLD) GO TO 80	HAFSTEP	60
	DPDD(J)=(RH-RHOLD-DPDE(J)*SSC)/(DH-DOLD)	HAFSTEP	61
80	IF (DPDD(J) .LE. 0. .OR. DPDD(J) .GT. 1.5*DPDDA) DPDD(J)=DPDDA	HAFSTEP	62
90	IF (NSC .EQ. 1) GO TO 140	HAFSTEP	63
	DOLD = DH \$ EOLD = EH	HAFSTEP	64
	DTN = DTNH	HAFSTEP	65
120	CONTINUE	HAFSTEP	66
	DTN = DTNS	HAFSTEP	67
	DTNH = DTNHS	HAFSTEP	68
140	CONTINUE	HAFSTEP	69
	RETURN	HAFSTEP	70
200	IF (NSPEC .NE. 0 .AND. SDURM .LT. 1.) EHL(J)=SSCALH(J)+EHL(J)	HAFSTEP	71
	DEPS=(DHL(J)-RH0(M))/DHL(J)	HAFSTEP	72
	SDH=MU(M)*DEPS	HAFSTEP	73
	QH=0. \$ DUH=U(J+1)-U(J) \$ CEF=CHL(J)-DUH/2	HAFSTEP	74
	IF (DUH .GT. 0.) GO TO 220	HAFSTEP	75
	CS=CHL(J)-DUH/2. \$ CF=CWQ(M)-CZQ(M)*DUH/CS	HAFSTEP	76
	QH=-0.5*(CWQ(M)*CS-CZQ(M)*DUH)*DUH*(DH+DOLD)	HAFSTEP	77
	CEF=CS*(1.+CF*(1.+0.5*CF))	HAFSTEP	78
	GO TO 230	HAFSTEP	79
220	QH=-0.5*C2(M)*CHL(J)*DUH*(DH+DOLD)	HAFSTEP	80
230	PHL(J)=DEPS*(EQSTC(M)+DEPS*(EQSTD(M)+DEPS*EQSTS(M)))*(1.-0.5*	HAFSTEP	81
	1 EQSTG(M)*(DHL(J)/RH0(M)-1.))+RH0S(M)*EQSTG(M)*EHL(J)	HAFSTEP	82
	SHL(J)=PHL(J)+SDH \$ RH=RHL(J)=SHL(J)+QH	HAFSTEP	83
	RETURN	HAFSTEP	84
	END	HAFSTEP	85

SUBROUTINE HDATA

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SUBROUTINE HDATA(H)
  INTEGER H
  DIMENSION H(200,3)
  READ 1000,A1,J1,I1,K1,A2,J2,I2,K2
  PRINT 1000,A1,J1,I1,K1,A2,J2,I2,K2
  H(J1,I1)=K1
  IF (J2 .EQ. 0) RETURN
  H(J2,I2)=K2
  RETURN
1000 FORMAT(2(A10,2I5,5X,R5))
END

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HDATA 2
HDATA 3
HDATA 4
HDATA 5
HDATA 6
HDATA 7
HDATA 8
HDATA 9
HDATA 10
HDATA 11
HDATA 12

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SUBROUTINE HSTRESS

C	SUBROUTINE HSTRESS	HSTRESS	2
C	THIS ROUTINE CONTROLS SWITCHING BETWEEN EQUATIONS OF STATE	HSTRESS	3
C	COMPUTES R,S,P FOR THE HALFSTEP POINT BETWEEN J AND J+1	HSTRESS	4
C	INPUT - J, M, DOLD, EOLD, UH, DH, EH.	HSTRESS	5
C	OUTPUT - RH, SHL, PHL, YHL, H, C.	HSTRESS	6
C		HSTRESS	7
C	INTEGER H,POROUS,PRESS,RINTER,SOLID,SPALL	HSTRESS	8
C	REAL MATL,NEM,NET,NEMH,NETH	PUFCOM	2
C	MISCELLANEOUS	PUFCOM	3
C	COMMON AZERO(1),CEF,CKS,DAVG,DELTIM,DISCPT(10),DOLD,DRHO,DTMAX,	PUFCOM	4
1	DTMIN,DTN,DTNH,DU,DX,EOLD,F,FAC,FIRST,J,JCYCS,JINIT,	PUFCOM	5
2	JFIN,JREZON(15),JSMAX,JSTAR,JTS,LSUB(30),M,MAXPR(30),N,NCYCS,	PUFCOM	6
3	NEDIT,NPERN,NR,NREZON,NSCRB(6),NSEPRAT,NSPALL,NTEDT,	PUFCOM	7
4	NTEX,NTR(15),POLD,P6(20),R(30),RLAST,SLAST,SMAX,TEDIT(50),	PUFCOM	8
5	TF,TIME,TJ,TREZON,TS,T6(20),ULAST,UOLD,UZERO,XLAST,XNOW,XOLD	PUFCOM	9
1	,XJDIT(20),MS	PUFCOM	10
C	HALFSTEP VALUES	PUFCOM	11
C	COMMON DH,DHLAST,DUH,EH,PH,RH,RHLAST,SH,SHLAST,UH,UHLAST,XH,XHLAST	PUFCOM	12
1	,NEMH,NETH	PUFCOM	13
C	CONDITION INDICATORS	PUFCOM	14
C	COMMON INF,LINTER,MIRROR,NORMAL,POROUS,PRESS,RINTER,SOLID,SPALL	PUFCOM	15
C	CELL LAYOUT	PUFCOM	16
C	COMMON DX(30),JBND(30),JMAT(30),NAUTO,MATL(6,2),NLAYER,NMTRLS,	PUFCOM	17
1	THK(30)	PUFCOM	18
C		PUFCOM	19
C	COORDINATE ARRAYS	PUFCOM	20
C	COMMON/COORD/X(200),X0(200),CHL(200),DHL(200),DPDD(200),DPDE(200),	COORDCOM	2
1	EHL(200),H(200,3),NEM(200),NET(200),PHL(200),RHL(200),SDT(200),	COORDCOM	3
2	SHL(200),T(200),U(200),YHL(200),ZHL(200)	COORDCOM	4
C	NAMED COMMON	COORDCOM	5
C	REAL MU,MUM	EQSTCOM	2
C	COMMON /EQS/ EQSTA(6),EQSTC(6),EQSTD(6),EQSTE(6),EQSTO(6),	EQSTCOM	3
1	EQSTH(6),EQSTN(6),EQSTS(6),EQSTV(6),CZQ(6),CWQ(6),C2(6)	EQSTCOM	4
C	COMMON /MELT/ EMELT(6,8),OMELT(6,8),SPH(6),THERM(6,8)	EQSTCOM	5
C	COMMON /RHO/ RHO(6),RHOS(6)	EQSTCOM	6
C	COMMON /TSR/ TSR(6,30),EXMAT(6,20),TENS(6,3)	EQSTCOM	7
C	COMMON /Y/ YO(6),YADD(6),MU(6),MUM,YADDM	EQSTCOM	8
C	COMMON /IND/ IECS(6),INDK(20),NALPHA,NCMP(6),NFR(6),NFOR(6),	EQSTCOM	9
1	NDS(6),NPR(6),NCON(6),NVAR(6)	INDCOM	2
C	COMMON /RAD/ SSTOP(9),START(9),SDURM,SSTOPM,NSPEC,SSJ,JSS,IPL0T(4)	INDCOM	3
1	,XMAX(4),XMIN(4),YMAX(4),YMIN(4),IA(7),ITITLE(24),NARZ,TARZ	RADCOM	2
C	COMMON /PES/ LVMAX,LVTOT,LVAR(200),COM(4000)	RADCOM	3
C	COMMON /ESC/ ESC(6,20)	HSTRESS	14
C	DATA MM/O/	HSTRESS	15
C		HSTRESS	16
C	ABORT FOR NEGATIVE DENSITY	HSTRESS	17
C	IF (DH .GT. 0.) GO TO 25	HSTRESS	18
C	WRITE (6,4990) N,J,DH,TIME \$ LSUB(7)=1 \$ RETURN	HSTRESS	19
C	COMPUTE THERMAL STRENGTH REDUCTION AND OLD DEVIATOR STRESS	HSTRESS	20
25	F=1.	HSTRESS	21
C	IF (N .EQ. 0) GO TO 30	HSTRESS	22
C	IF (MM .EQ. 1000*M+N) GO TO 30	HSTRESS	23
C	IF (THERM(M,1) .EQ. 0.) GO TO 27	HSTRESS	24
C	EMELT(M,1)=THERM(M,6)+(THERM(M,1)-THERM(M,6))*EXP((-TIME+0.5*DTNH)	HSTRESS	25
1	/THERM(M,2))	HSTRESS	26
27	MM=1000*M+N	HSTRESS	27
C	IF (THERM(M,3) .EQ. 0.) GO TO 30	HSTRESS	28
C	EQSTE(M)=THERM(M,8)+(THERM(M,3)-THERM(M,8))*EXP((-TIME+0.5*DTNH)	HSTRESS	29
1	/THERM(M,4))	HSTRESS	30
30	IF (EH .LT. EMELT(M)) IE=1	HSTRESS	31
C	IF (H(J,3) .EQ. 5R M .AND. IE .EQ. 1) H(J,3)=5R E	HSTRESS	32
C	IF (EMELT(M,1) .GT. 1.E20) GO TO 34	HSTRESS	33
C	IF (THERM(M,1) .EQ. 0.) GO TO 33	HSTRESS	34
C	CALL TMELT(0,M,EH,F,F0)	HSTRESS	35
C	IF (OMELT(M,1) .NE. 0.) CALL TMELT(1,M,EH,F,F0)	HSTRESS	36
C	GO TO 34	HSTRESS	37
33	CALL FMELT(4,M,EH,F,F0,X)	HSTRESS	38
34	IF (F .EQ. 0.) H(J,3)=5R M	HSTRESS	39
C	MUM=MU(M)*F0	HSTRESS	40
C	IF (EXMAT(M,4) .NE. 0.) MUM=(MU(M)+(DH-RHOS(M))*EXMAT(M,4))*F0	HSTRESS	41
C	T(J)=TENS(M,1)*F	HSTRESS	42
C	YADDM=YADD(M)	HSTRESS	43
C	CZJ=CZQ(M)	HSTRESS	44
C	CWJ=CWQ(M)	HSTRESS	45
C		HSTRESS	46

SUBROUTINE HSTRESS (Continued)

	DUH=U(J+1)-U(J)	HSTRESS	47
	DUHM=DUH	HSTRESS	48
	DT=0.5*(DTN+DTNH)	HSTRESS	49
	IF (NALPHA .GT. 1) DUHM=-2.*DX/DH*(DH-DOLD)/(DTN+DTNH)	HSTRESS	50
C		HSTRESS	51
C	STRAIN CALCULATIONS AND DEFINITION OF DEVIATOR STRESSES FROM	HSTRESS	52
C	FROM PREVIOUS CYCLE. STRAINS AND STRESS DEVIATORS ARE	HSTRESS	53
C	POSITIVE IN TENSION.	HSTRESS	54
	TXY=0.	HSTRESS	55
	ROT=0.	HSTRESS	56
	K=1	HSTRESS	57
	DROT=0.	HSTRESS	58
	EXY=0.	HSTRESS	59
	EV=-2.*(DH-DOLD)/(DH+DOLD)	HSTRESS	60
	SDH=SHL(J)-PHL(J)	HSTRESS	61
	SX=-SDH	HSTRESS	62
	IF (N .LE. 1) EXEN=EYEN=EZEN=0.	HSTRESS	63
	IF (NSCRB(6) .EQ. 0 .OR. MOD(N,NEDIT) .NE. 1) GO TO 45	HSTRESS	64
	DXO=XO(J+1)-XO(J)	HSTRESS	65
	EXEN=(DX-DXO)/DXO	HSTRESS	66
	IF (NALPHA .EQ. 1) GO TO 45	HSTRESS	67
	XOS=XO(J+1)+XO(J)	HSTRESS	68
	EYEN=(X(J+1)+X(J)-XOS)/XOS	HSTRESS	69
45	CONTINUE	HSTRESS	70
	GO TO (50,60,70)NALPHA	HSTRESS	71
C	PLANAR GEOMETRY	HSTRESS	72
50	EX=EV	HSTRESS	73
	EY=0.	HSTRESS	74
	EZ=0.	HSTRESS	75
	SY=SDH/2.	HSTRESS	76
	SZ=SY	HSTRESS	77
	GO TO 80	HSTRESS	78
C	CYLINDRICAL GEOMETRY	HSTRESS	79
60	EX=DUH*DT/DX	HSTRESS	80
	EY=EV-EX	HSTRESS	81
	EZ=0.	HSTRESS	82
	SY=-SDT(J)	HSTRESS	83
	SZ=-(SX+SY)	HSTRESS	84
	GO TO 80	HSTRESS	85
C	SPHERICAL GEOMETRY	HSTRESS	86
70	EX=DUH*DT/DX	HSTRESS	87
	EY=(EV-EX)/2.	HSTRESS	88
	EZ=EY	HSTRESS	89
	SY=SDH/2.	HSTRESS	90
	SZ=SY	HSTRESS	91
	EZEN=EYEN	HSTRESS	92
80	CONTINUE	HSTRESS	93
	IF (NSCRB(6) .EQ. 0 .OR. MOD(N,NEDIT) .NE. 1) GO TO 100	HSTRESS	94
	TCX=PHL(J)-SX \$ TCY=PHL(J)-SY \$ TCZ=PHL(J)-SZ	HSTRESS	95
	ECXEN=-EXEN \$ EYEN=-EYEN \$ ECZEN=-EZEN	HSTRESS	96
	PRINT 81,N,J,TCX,TCY,TCZ,PHL(J),ECXEN,EYEN,ECZEN	HSTRESS	97
81	FORMAT(* N,J=*214,* TCX,TCY,TCZ,PHL=*1P4E10.3,* ENG. STRAINS	HSTRESS	98
	1 ECX,ECY,ECZ=*3E10.3)	HSTRESS	99
C		HSTRESS	100
C	**** ROUTES FOR COMPOSITE, POROUS, AND FRACTURE MODELS ****	HSTRESS	101
C		HSTRESS	102
100	IF (NCMP(M)+NFR(M)+NPR(M) .EQ. 0) GO TO 200	HSTRESS	103
	IF (NCMP(M) .EQ. 0) GO TO 130	HSTRESS	104
C		HSTRESS	105
C	ROUTE FOR COMPOSITE MODEL	HSTRESS	106
C		HSTRESS	107
C	-- REBAR --	HSTRESS	108
	L=LVAR(J)	HSTRESS	109
	CALL REBAR(1,5,J,J,M,N,H(J,1),DH,DOLD,SX,SY,SZ,TXY,EH,PHL(J),EX,	HSTRESS	110
	1EY,EZ,EXY,F,0.,0.,ESC,COM(L),COM(L+1),COM(L+3),NEM(J),NET(J),	HSTRESS	111
	2 YHL(J),COM(L+2),0)	HSTRESS	112
	SDH=-SX	HSTRESS	113
	SDT(J)=-SY	HSTRESS	114
	GO TO 400	HSTRESS	115
C	ROUTE FOR POROUS MODEL	HSTRESS	116
130	IF (NPR(M) .EQ. 0) GO TO 160	HSTRESS	117
	IF (NPR(M) .EQ. 3) GO TO 135	HSTRESS	118
	IF (H(J,1) .GE. SOLID) GO TO 200	HSTRESS	119
	IF (F .GT. 0.) GO TO 135	HSTRESS	120
	H(J,1)=SOLID \$ GO TO 200	HSTRESS	121

SUBROUTINE HSTRESS (Continued)

135	CONTINUE	HSTRESS	122
	NPORM=NPOR(M)	HSTRESS	123
	GO TO (140,145,150,155) NPORM	HSTRESS	124
C		HSTRESS	125
C	-- POREQST --	HSTRESS	126
140	CALL POREQST(1,5,M,CHL(J),DH,DOLD,EH,EOLD,F,PHL(J),CZJ,CWJ,H(J,1),	HSTRESS	127
	1 DPDE(M),EQSTC(M),EQSTD(M),EQSTG(M),EQSTS(M),MUM,RHOS(M),	HSTRESS	128
	2 YADDM,NDS(M),NPR(M),J)	HSTRESS	129
	GO TO 310	HSTRESS	130
145	CONTINUE	HSTRESS	131
C		HSTRESS	132
C	-- PORHOLT --	HSTRESS	133
	CALL PORHOLT(1,5,M,CHL(J),DH,DOLD,EH,EOLD,F,PHL(J),H(J,1),J,	HSTRESS	134
	1 DPDE(J),EQSTC(M),MUM,YADDM,RHOS(M),DT)	HSTRESS	135
	GO TO 310	HSTRESS	136
150	NPRM = NPR(M)+1	HSTRESS	137
C		HSTRESS	138
C	-- PEST --	HSTRESS	139
	L=LVAR(J)	HSTRESS	140
	MUM=1.333*MUM	HSTRESS	141
	CALL PEST(2,5,NPRM,H(J,1),J,T(J),DT,M,CHL(J),DH,	HSTRESS	142
	1 DOLD,RHOS(M),COM(L),PHL(J),COM(L+1),	HSTRESS	143
	2 COM(L+2),EH,EOLD,F,EQSTC(M),EQSTD(M),EQSTS(M),	HSTRESS	144
	3 EQSTG(M),MUM,YADDM,COM(L+3),COM(L+4),CZJ,	HSTRESS	145
	4 CWJ,EQSTH(M),EQSTE(M),EQSTN(M),EQSTV(M),	HSTRESS	146
	5 EQSTA(M),DPDD(J),DPDE(J),N)	HSTRESS	147
	MUM= 0.75 * MUM	HSTRESS	148
	GO TO 300	HSTRESS	149
155	SX=SX-PHL(J)	HSTRESS	150
	SY=SY-PHL(J)	HSTRESS	151
	SZ=SZ-PHL(J)	HSTRESS	152
C		HSTRESS	153
C	-- CAP1 --	HSTRESS	154
C	SX,SY,SZ ARE TOTAL STRESSES POSITIVE IN TENSION	HSTRESS	155
157	CALL CAP1(LSUB(8), IN,M,N,H(J,1),DH,DOLD,EH,EX,EY,EZ,EXY,F,	HSTRESS	156
	1 EQSTG(M),RHOS(M),SX,SY,SZ,TTY,NEM(J),K,J,NET(J))	HSTRESS	157
	PHL(J)=- (SX+SY+SZ)/3.	HSTRESS	158
	SDH=-SX-PHL(J)	HSTRESS	159
	SDT(J)=-SY-PHL(J)	HSTRESS	160
	GO TO 400	HSTRESS	161
C	ROUTES FOR FRACTURE MODELS	HSTRESS	162
160	NFRM=NFR(M)+1	HSTRESS	163
	GO TO (200,170,175,180,180,195)NFRM	HSTRESS	164
C		HSTRESS	165
C	-- DFRACT --	HSTRESS	166
170	IF (PHL(J) .GT. TSR(M,5) .AND. H(J,3) .LT. 3)GO TO 200	HSTRESS	167
	CALL DFRACT(SX,SY,SZ,TTY,EX,EY,EZ,EXY,PHL(J),NEM(J),NET(J),	HSTRESS	168
	1 DH,DOLD,DT,EOLD,EH,EQSTC(M),EQSTG(M),MUM,RHOS(M),TSR,YHL(J),	HSTRESS	169
	2 YADDM,F,M,J,K,DRGT)	HSTRESS	170
	SHL(J)=-SX+PHL(J)	HSTRESS	171
	SDT(J)=-SY	HSTRESS	172
	H(J,3)=3	HSTRESS	173
	GO TO 410	HSTRESS	174
C		HSTRESS	175
C	-- FRAG --	HSTRESS	176
175	IF (H(J,3) .GE. 3) GO TO 177	HSTRESS	177
	STENS=AMAX1(SX,SY,SZ)	HSTRESS	178
	IF (-STENS+PHL(J) .GT. TSR(M,5)) GO TO 200	HSTRESS	179
	H(J,3)=3	HSTRESS	180
	LVAR(J)=LVMAX	HSTRESS	181
	LVMAX=LVMAX+NVAR(M)	HSTRESS	182
	IF (LVMAX .LE. LVTOT+1) GO TO 177	HSTRESS	183
	LSUB(7)=1	HSTRESS	184
	PRINT 1177,N,J,TIME	HSTRESS	185
1177	FORMAT(* FRAG EXCEEDED STORAGE AT N=*14,* J=*13,* TIME=*1PE10.3)	HSTRESS	186
177	LS=1	HSTRESS	187
	IF (MOD(N,NEDIT) .EQ. 0) LS=2	HSTRESS	188
	L=LVAR(J)	HSTRESS	189
	CALL FRAG(LS,5,M,J,J,N,H(J,3),EQSTC(M),DH,DOLD,DT,EH,EOLD,EX,EY,	HSTRESS	190
	1 EXY,F,NEM(J),MUM,EQSTG(M),RHOS(M),ROT,DRGT,PHL(J),SX,SY,TTY,	HSTRESS	191
	2 YHL(J),EXMAT(M,1),TSR,COM(L),COM(L+5),COM(L+10),COM(L+15),	HSTRESS	192
	3 COM(L+20))	HSTRESS	193
	SDH=-SX	HSTRESS	194
	SDT(J)=-SY	HSTRESS	195
	LSUB(12)=1	HSTRESS	196

SUBROUTINE HSTRESS (Continued)

C	GO TO 400	HSTRESS	197
C	-- SHEAR1 --	HSTRESS	198
180	IF(H(J,3)-2)177,181,183	HSTRESS	199
181	IF(NFR(M).EQ.3)GO TO 183	HSTRESS	200
	STENS=AMAX1(SX,SY,SZ)	HSTRESS	201
	IF(-STENS.LT. TSR(M,5)*TSR(M,9).AND. -STENS+PHL(J).LT. TSR(M,8)	HSTRESS	202
1	)GO TO 177	HSTRESS	203
183	LS=2	HSTRESS	204
	IF (MOD(N,NEDIT).EQ. 0) LS=3	HSTRESS	205
	L=LVAR(J)	HSTRESS	206
	CALL SHEAR2(LS,5,M,J,J,H(J,3),SX,SY,SZ,TSR,PHL(J),COM(L),DH,DOLD,	HSTRESS	207
1	DT,EH,EOLD,COM(L+1),EMELT(M,1),COM(L+2),EX,EY,EZ,EXY,F,YHL(J),	HSTRESS	208
2	COM(L+3),ROT,ROT,ESC,COM(L+4))	HSTRESS	209
	SDH=-SX	HSTRESS	210
	SDT(J)=-SY	HSTRESS	211
	GO TO 400	HSTRESS	212
C	-- BFRAC1 --	HSTRESS	213
C	-- BFRAC1 --	HSTRESS	214
195	IF(H(J,3).NE.2)GO TO 197	HSTRESS	215
	STENS=AMAX1(SX,SY,SZ)	HSTRESS	216
	IF (N.EQ. 0) GO TO 200	HSTRESS	217
	IF (-STENS.GT. TSR(M,5)*TSR(M,9).OR. -STENS+PHL(J).GT. TSR(M,8)	HSTRESS	9/12/79 12
1	)GO TO 200	HSTRESS	218
	H(J,3)=1	HSTRESS	219
197	SY=-SY	HSTRESS	220
	SZ=-SZ	HSTRESS	221
	LS=LSUB(12)	HSTRESS	222
	IF (LS.NE. 0.AND. MOD(N,NEDIT).EQ. 0) LS=2	HSTRESS	223
	L=LVAR(J)	HSTRESS	224
	CALL BFRAC1(LS,SDH,SY,SZ,TSR,-EX,-EY,-EZ,-EXY,PHL(J),NEM(J),NET(J)	HSTRESS	225
1	RHOS(M)/DH,RHOS(M)/DOLD,DT,EOLD,EH,EQSTC(M),EQSTG(M),MUM,TSR,	HSTRESS	226
2	YHL(J),YADDM,F,1,J,M,N,RHOS(M),DROT,ROT,COM(L),COM(L+1),COM(L+6)	HSTRESS	227
3	)	HSTRESS	228
	SDT(J)=-SY	HSTRESS	229
199	LSUB(12)=1	HSTRESS	230
	GO TO 400	HSTRESS	231
C	**** ROUTES FOR PRESSURE CALCULATION ****	HSTRESS	232
C	**** ROUTES FOR PRESSURE CALCULATION ****	HSTRESS	233
C	**** ROUTES FOR PRESSURE CALCULATION ****	HSTRESS	234
200	NPRM = NPR(M)+1	HSTRESS	235
	GO TO (270,220,230,240,250,255,260,270) NPRM	HSTRESS	236
C	EQUATION OF STATE FOR EXPLOSION PRODUCTS	HSTRESS	237
220	IF (NEM(J).GE. 0.999999) GO TO 270	HSTRESS	238
	QH=0. \$ IF(DUHM.LT. -1.) QH=(CZJ*DUHM-CWJ*CHL(J))*DUHM*DH	HSTRESS	239
	L=LVAR(J)	HSTRESS	240
	CALL EXPLODE(3,5,M,EHL,DHL,DOLD,PHL,SHL,NEM,X,J,QH,TIME,DT)	HSTRESS	241
	EH=EHL(J)	HSTRESS	242
	GO TO 305	HSTRESS	243
C	SIMPLE, EXTENDED EQUATION OF STATE	HSTRESS	244
230	CALL ESA(1,5,M,CHL(J),DH,EH,PHL(J),DPDD(J),DPDE(J))	HSTRESS	245
	GO TO 300	HSTRESS	246
C	PHILCO-FORD EQUATION OF STATE	HSTRESS	247
240	CALL EQSTPF(1,5,M,CHL(J),DH,EH,PHL(J))	HSTRESS	248
	GO TO 300	HSTRESS	249
C	VARIABLE MODULI EQN. OF STATE	HSTRESS	250
C	(IMPLEMENTED FOR PLANAR AND SPHERICAL CASES ONLY)	HSTRESS	251
250	EPS=EMU=ALOG(DH/RHO(M))	HSTRESS	252
	IF (NALPHA.NE. 3) GO TO 252	HSTRESS	253
	L=LVAR(J)	HSTRESS	254
	IF (COM(L).EQ. 0.) COM(L)=X(J)	HSTRESS	255
	EPS=EMU+3.*ALOG((X(J)+U(J)*DTNH/2.)/COM(L))	HSTRESS	256
252	NEM(J)=EMU	HSTRESS	257
	NET(J)=EPS	HSTRESS	258
	CALL HYP0(1,IN,M,CHL(J),DH,EMU,COM(L+1),EPS,COM(L+2),J,PHL(J),SDH)	HSTRESS	259
	GO TO 400	HSTRESS	260
C	LLL*S 3-PHASE EQUATION OF STATE OF ROYCE	HSTRESS	261
255	CALL GRAY(1,IN,M,MUM,EMELT(M,1),DH,EH,CHL(J),PHL(J),DPDD(J),	HSTRESS	262
1	DPDE(J),H(J,1))	HSTRESS	263
	GO TO 305	HSTRESS	264
C	SANDIA TABULAR EQUATION OF STATE	HSTRESS	265
260	CALL EQSTAB(1,IN,DH,EH,PHL(J))	HSTRESS	266
	GO TO 300	HSTRESS	267
C	MIE-GRUNEISEN AND PUFF EXPANSION EQUATIONS OF STATE	HSTRESS	268
270	CALL EQST(EH,DH,PHL(J),M,CHL(J),DPDD(J),DPDE(J))	HSTRESS	269
		HSTRESS	270
		HSTRESS	271
		HSTRESS	272
		HSTRESS	273

SUBROUTINE HSTRESS (Continued)

C		HSTRESS	274
C	**** ROUTES FOR DEVIATOR STRESS CALCULATION ****	HSTRESS	275
C		HSTRESS	276
300	IF (MUM .GT. 0. .AND. YHL(J)*F .GT. 0. .AND. NPR(M) .NE. 1) GO TO	HSTRESS	277
1	310	HSTRESS	278
C	MATERIAL IS MELTED OR HOTTER - NO DEVIATOR STRESS	HSTRESS	279
305	SDH=0. \$ GO TO 400	HSTRESS	280
310	IF (NDS(M) .GT. 0) GO TO 320	HSTRESS	281
C	COULOMB-MISES YIELD WITH WORK HARDENING	HSTRESS	282
	IF (NALPHA .GT. 1) GO TO 312	HSTRESS	283
	SDH=SDH-1.333*MUM*EV	HSTRESS	284
	GO TO 318	HSTRESS	285
312	SDH=SDH-2.0*MUM*(EX-EV/3.)	HSTRESS	286
	IF (NALPHA .NE. 2) GO TO 318	HSTRESS	287
	SDT(J)=SDT(J)-1.333*MUM*(EV-1.5*EX)	HSTRESS	288
	SN=SQRT(3.*(SDH*SDH+SDT(J)*SDT(J)+SDH*SDT(J)))	HSTRESS	289
	IF (SN .LT. (YHL(J)+EXMAT(M,1)*PHL(J))*F) GO TO 400	HSTRESS	290
	YHL(J)=AMIN1(AMAX1(SN,YHL(J)),YHL(J)+YADD*ABS(DH-DOLD))	HSTRESS	291
	EL=(YHL(J)+EXMAT(M,1)*PHL(J))*F/SN	HSTRESS	292
	SDH=EL*SDH \$ SDT(J)=EL*SDT(J) \$ GO TO 400	HSTRESS	293
318	CONTINUE	HSTRESS	294
	IF (ABS(SDH) .LT. 0.6667*(YHL(J)+EXMAT(M,1)*PHL(J))*F) GO TO 400	HSTRESS	295
	YHL(J)=AMIN1(AMAX1(ABS(1.5*SDH),YHL(J)),YHL(J)+YADD*ABS(DH-DOLD))	HSTRESS	296
	SDH=SIGN(0.6667*(YHL(J)+EXMAT(M,1)*PHL(J))*F,SDH)	HSTRESS	297
	GO TO 400	HSTRESS	298
C	PREPARE FOR COMPLEX YIELD MODELS	HSTRESS	299
320	DRHO=DH-DOLD	HSTRESS	300
	OMUM=MUM	HSTRESS	301
	COEF=-2.0*MUM*(EX-EV/3.)	HSTRESS	302
	IF (NALPHA .EQ. 2) GO TO 323	HSTRESS	303
	DRHO=COEF*(DH+DOLD)/2.667/MUM	HSTRESS	304
	GO TO 325	HSTRESS	305
323	DSR=SDH+COEF	HSTRESS	306
	DST=SDT(J)-1.333*MUM*(EV-1.5*EX)	HSTRESS	307
	SNE=0.6667*SQRT(3.*(DSR*DSR+DST*DST+DSR*DST))	HSTRESS	308
	SN=0.6667*SQRT(3.*(SDH*SDH+SDT(J)*SDT(J)+SDT(J)*SDH))	HSTRESS	309
	COEF=SNE-SNO	HSTRESS	310
	DRHO=COEF*(DH+DOLD)/2.667/MUM	HSTRESS	311
	SDHO=SDH \$ SDH=SN	HSTRESS	312
325	CONTINUE	HSTRESS	313
	NDSM=NDS(M)	HSTRESS	314
	GO TO (330,340,340,330,350,360,370) NDSM	HSTRESS	315
C	ONE- AND TWO-PARAMETER RELAXATION MODELS (NDS=1, 4)	HSTRESS	316
330	CALL RELAX(H(J,3),SDH,YHL(J),DRHO,COEF,N,J,M,NEM(J),NET(J),DT,	HSTRESS	317
1	TSR,YADD,M,YO(M),NDSM)	HSTRESS	318
	GO TO 390	HSTRESS	319
C	BAND AND GILMAN RELAXATION MODELS (NDS=2, 3)	HSTRESS	320
340	CALL BANDRLX(H(J,3),SDH,YHL(J),DRHO,COEF,N,J,M,NEM(J),NET(J),DT,	HSTRESS	321
1	TSR,MUM,YADD,M,NDSM)	HSTRESS	322
	GO TO 390	HSTRESS	323
C	BAUSCHINGER EFFECT MODEL (NDS=5)	HSTRESS	324
350	MUM=(MU(M)+TSR(M,19)*(DH/RHO(M)-1.))*F	HSTRESS	325
	COEF=2.*MUM*DRHO/(DH+DOLD)	HSTRESS	326
	CALL BAUSCHI(H(J,3),SDH,COEF,NEM(J),YHL(J),NET(J),TSR(M,15),TSR(M,	HSTRESS	327
1	16),TSR(M,17),TSR(M,18),MUM)	HSTRESS	328
	CSQ=CHL(J)**2+AMAX1(0.,(MUM-OMUM)*2./(DH+DOLD))	HSTRESS	329
	CHL(J)=0.5*(CSQ/CHL(J)+CHL(J))	HSTRESS	330
	GO TO 390	HSTRESS	331
C	READ RELAXATION MODEL FOR BERYLLIUM (NDS=6)	HSTRESS	332
360	CALL STRES2(LSUB(13),0,H(J,3),M,J,N,DH,DOLD,RHO(M),SDH,MUM,F,DT,	HSTRESS	333
1	NEM(J),NET(J),TSR)	HSTRESS	334
	GO TO 390	HSTRESS	335
C	NONLINEAR WORK-HARDENING.	HSTRESS	336
370	SZ=-SZ	HSTRESS	337
	CALL EP(1,M,N,SDH,SDT(J),SZ,TSR,YHL(J),-EX,-EY,-EZ,-EXY,MUM,	HSTRESS	338
1	NEM(J))	HSTRESS	339
C		HSTRESS	340
C	**** ARTIFICIAL VISCOSITY AND RESULTANT STRESS ****	HSTRESS	341
C		HSTRESS	342
390	IF (NALPHA .NE. 2) GO TO 400	HSTRESS	343
C	ADJUSTMENTS FOR DEVIATORS IN CYLINDRICAL CASE	HSTRESS	344
	EL=SDH/SNE \$ SDH=EL*DSR \$ SDT(J)=EL*DST	HSTRESS	345
400	SHL(J)=PHL(J)+SDH	HSTRESS	346
	IF (H(J,1) .EQ. SOLID .AND. (DH/RHO(M)-1.) .GT. 0.)SHL(J) =	HSTRESS	347
1	PHL(J)+SDH*(1.-0.5*EQSTG(M)*(DH/RHO(M)-1.)/AMAX1(D,0.01,F))	HSTRESS	348

SUBROUTINE HSTRESS (Concluded)

410	RH=SHL(J) \$ CEF=CHL(J)	HSTRESS	349
	IF (DUHM .GE. -1.) GO TO 450	HSTRESS	350
	CF=CWJ-CZJ*DUHM/CHL(J)	HSTRESS	351
	CEF=CHL(J)*(1.+CF*(1.+0.5*CF))-DUH/2.	HSTRESS	352
	IF (CF .GT. 1.0) CEF=CHL(J)*(2.*CF+0.5/CF)-DUH/2.	HSTRESS	353
	GO TO 470	HSTRESS	354
450	CF=C2(M)	HSTRESS	355
470	RH=SHL(J)-CF*CHL(J)*DUHM*DH	HSTRESS	356
	IF (RH.LT.0. .AND. F.LE.0. .AND. NSEPRAT.EQ.0) RH=SHL(J)=PHL(J)=0.	HSTRESS	357
C	SPALL PROVISIONS	HSTRESS	358
	IF (NFR(M) .GT. 0) GO TO 550	HSTRESS	359
	SHLSV=SHL(J)	HSTRESS	360
	PHLSV=PHL(J)	HSTRESS	361
	IF (RH .LT. T(J)) GO TO 515	HSTRESS	362
	IF (NALPHA .EQ. 2) GO TO 505	HSTRESS	363
	IF (PHL(J) -SDH/2. .LT. T(J)) GO TO 520	HSTRESS	364
	GO TO 550	HSTRESS	365
505	IF (PHL(J) +SDT(J) .LT. T(J)) GO TO 525	HSTRESS	366
	IF (2.*PHL(J)-SDT(J)-SHL(J).LT.T(J))GO TO 530	HSTRESS	367
	GO TO 550	HSTRESS	368
515	SHL(J)=PHL(J)=RH=0.	HSTRESS	369
	GO TO 535	HSTRESS	370
C	SPALL BY LATERAL STRESS,NALPHA=1,3	HSTRESS	371
520	RF=(3.*PHL(J)-SHL(J))/2./(EQSTC(M)+1.333*MUM)	HSTRESS	372
	DP=EQSTC(M)*RF	HSTRESS	373
	DS=MUM*RF	HSTRESS	374
	Q=RH-SHL(J)	HSTRESS	375
	SHL(J)=SHL(J)-DP+DS/2.	HSTRESS	376
	RH=SHL(J)+Q	HSTRESS	377
	PHL(J)=PHL(J)-DP	HSTRESS	378
	GO TO 535	HSTRESS	379
C	SPALL BY THETA STRESS,NALPHA=2	HSTRESS	380
525	RF=(PHL(J)+SDT(J))/(EQSTC(M)+1.333*MUM)	HSTRESS	381
	DP=EQSTC(M)*RF	HSTRESS	382
	DS=MUM*RF	HSTRESS	383
	PHL(J)=PHL(J)-DP	HSTRESS	384
	Q=RH-SHL(J)	HSTRESS	385
	SHL(J)=SHL(J)-DP+DS/2.	HSTRESS	386
	RH=SHL(J)+Q	HSTRESS	387
	SDT(J)=-PHL(J)	HSTRESS	388
	GO TO 535	HSTRESS	389
C	SPALL BY Z STRESS, NALPHA=2	HSTRESS	390
530	RF=(2.*PHL(J)-SDT(J)-SHL(J))/(EQSTC(M)+1.333*MUM)	HSTRESS	391
	DP=EQSTC(M)*RF	HSTRESS	392
	DS=MUM*RF	HSTRESS	393
	Q=RH-SHL(J)	HSTRESS	394
	PHL(J)=PHL(J)-DP	HSTRESS	395
	SHL(J)=SHL(J)-DP+DS/2.	HSTRESS	396
	SDT(J)=SDT(J)+DS/2.	HSTRESS	397
	RH=SHL(J)+Q	HSTRESS	398
535	CONTINUE	HSTRESS	399
	PRINT 4992,J,N,SHL(J),PHL(J),RH,Q,SDT(J),DP,DS,SHLSV,PHLSV	HSTRESS	400
4992	FORMAT(* ---J=*13,* N=*13,* SHL,PHL,RH,Q=*1P4E11.3,* SDT,DP,DS=*	HSTRESS	401
1	1P3E11.3/* SHLSV,PHLSV=*1P2E11.3)	HSTRESS	402
	IF (H(J,2) .GT. 0 .AND. H(J,2) .LT. 77B) GO TO 550	HSTRESS	403
	IF (H(J,2) .NE. NORMAL) GO TO 550	HSTRESS	404
	H(J,2)=NSPALL=NSPALL+1	HSTRESS	405
550	CONTINUE	HSTRESS	406
	RETURN	HSTRESS	407
4990	FORMAT(20H STOP IN HSTRESS, N=14,4H, J=14,4H, D=1PE10.3,	HSTRESS	408
1	7H, TIME=1PE10.3)	HSTRESS	409
	END	HSTRESS	410

SUBROUTINE HYDRO

C	SUBROUTINE HYDRO	HYDRO	2
C	SUBROUTINE CONTROLS THE MAIN CALCULATION CYCLE	HYDRO	3
C	* CONTAINS 6 PATHS -	HYDRO	4
C	1. NORMAL - COORDINATES WITHIN MATERIAL	HYDRO	5
C	2. INTERFACE - INTERFACE BETWEEN MATERIALS	HYDRO	6
C	3. INTERFACE SPALL - SEPARATED INTERFACE BETWEEN MATERIALS	HYDRO	7
C	4. MIRROR - FIRST COORDINATE FOR A SYMMETRIC IMPACT	HYDRO	8
C	5. PRESSURE - PRESSURE HISTORY APPLIED AT FRONT (J=1)	HYDRO	9
C	6. LEFT INTERFACE - DUMMY PATH	HYDRO	10
C	* CALLS HAFSTEP FOR HALFSTEP CALCULATIONS AT EACH COORDINATE	HYDRO	11
C	* CHECKS FOR SPALLING AND RECOMBINATION	HYDRO	12
C	* COMPUTES MINIMUM PERMITTED TIME STEP FOR NEXT CYCLE	HYDRO	13
C	INPUT - DTNH,DTN,FIRST,NCYCS.	HYDRO	14
C		HYDRO	15
C	NAMED COMMON	HYDRO	16
C	REAL MU,MUM	EQSTCOM	2
C	COMMON /EQS/ EQSTA(6),EQSTC(6),EQSTD(6),EQSTE(6),EQSTG(6),	EQSTCOM	3
C	1 EQSTH(6),EQSTN(6),EQSTS(6),EQSTV(6),CZQ(6),CWQ(6),C2(6)	EQSTCOM	4
C	COMMON /MELT/ EMELT(6,8),GMELT(6,8),SPH(6),THERM(6,8)	EQSTCOM	5
C	COMMON /RHO/ RHO(6),RHOS(6)	EQSTCOM	6
C	COMMON /TSR/ TSR(6,30),EXMAT(6,20),TENS(6,3)	EQSTCOM	7
C	COMMON /Y/ YO(6),YADD(6),MU(6),MUM,YADDM	EQSTCOM	8
C	COMMON /IND/ IEOS(6),INDK(20),NALPHA,NCMP(6),NFR(6),NPR(6),	EQSTCOM	9
C	1 NDS(6),NPR(6),NCON(6),NVAR(6)	INDCOM	2
C	COMMON /RAD/ SSTOP(9),START(9),SDURM,SSTOPM,NSPEC,SSJ,JSS,IPLDT(4)	INDCOM	3
C	1 ,XMAX(4),XMIN(4),YMAX(4),YMIN(4),IA(7),ITITLE(24),NARZ,TARZ	RADCOM	2
C		RADCOM	3
C	INTEGER H,POROUS,PRESS,RINTER,SOLID,SPALL	HYDRO	20
C	REAL MATL,NEM,NET,NEMH,NETH	PUFCOM	2
C	MISCELLANEOUS	PUFCOM	3
C	COMMON AZERO(1),CEF,CKS,DAVG,DELTIM,DISCPT(10),DOLD,DRHO,DTMAX,	PUFCOM	4
C	1 DTMIN,DTN,DTNH,DU,DX,EOLD,F,FAC,FIRST,J,JCYCS,JINIT,	PUFCOM	5
C	2 JFIN,JREZON(15),JSMAX,JSTAR,JTS,LSUB(30),M,MAXPR(30),N,NCYCS,	PUFCOM	6
C	3 NEDIT,NPERN,NR,NREZON,NSCRB(6),NSEPRAT,NSPALL,NTEDT,	PUFCOM	7
C	4 NTEX,NTR(15),POLD,P6(20),R(30),RLAST,SLAST,SMAX,TEDIT(50),	PUFCOM	8
C	5 TF,TIME,TJ,TREZON,TS,T6(20),ULAST,UOLD,UZERO,XLAST,XNOW,XOLD	PUFCOM	9
C	1 ,XJDIT(20),MS	PUFCOM	10
C	HALFSTEP VALUES	PUFCOM	11
C	COMMON DH,DHLAST,DUH,EH,PH,RH,RHLAST,SH,SHLAST,UH,UHLAST,XH,XHLAST	PUFCOM	12
C	1 ,NEMH,NETH	PUFCOM	13
C	CONDITION INDICATORS	PUFCOM	14
C	COMMON INF,LINTER,MIRROR,NORMAL,POROUS,PRESS,RINTER,SOLID,SPALL	PUFCOM	15
C	CELL LAYOUT	PUFCOM	16
C	COMMON DX(30),JBND(30),JMAT(30),NAUTO,MATL(6,2),NLAYER,NMTRLs,	PUFCOM	17
C	1 THK(30)	PUFCOM	18
C		PUFCOM	19
C	COORDINATE ARRAYS	PUFCOM	20
C	COMMON/COORD/X(200),X0(200),CHL(200),DHL(200),DPDD(200),DPDE(200),	COORDCOM	2
C	1 EHL(200),H(200,3),NEM(200),NET(200),PHL(200),RHL(200),SDT(200),	COORDCOM	3
C	2 SHL(200),T(200),U(200),YHL(200),ZHL(200)	COORDCOM	4
C		COORDCOM	5
C	IF (N.EQ. 1) ISPALL=0	HYDRO	23
C	1 DT=DTMIN=1.	HYDRO	24
C	SMAX=0.	HYDRO	25
C	**** ROUTINE TO RESET DTNH FOR SPALL CLOSURE ****	HYDRO	26
C	IF (NLAYER.LE. 1 .OR. ISPALL.EQ. 0) GO TO 82	HYDRO	27
C	NLM1=NLAYER-1	HYDRO	28
C	DO 80 LLL=1,NLM1	HYDRO	29
C	JB=JBND(LLI)	HYDRO	30
C	IF (JB.GT. JSTAR) GO TO 82	HYDRO	31
C	IF (H(JB+1,2).NE. SPALL) GO TO 80	HYDRO	32
C	IF (U(JB).EQ. U(JB+1)) GO TO 80	HYDRO	33
C	DTSP=(X(JB+1)-X(JB))/(U(JB)-U(JB+1))	HYDRO	34
C	IF (DTSP.GT. DTNH .OR. DTSP.LT. 0.) GO TO 80	HYDRO	35
C	DTNAT=AMIN1((X(JB)-X(JB-1))/CHL(JB-1),(X(JB+2)-X(JB+1))/CHL(JB+1))	HYDRO	36
C	DTNH=AMIN1(DTNH,AMAX1(DTSP,0.2*DTNAT))-0.001*DTNAT	HYDRO	37
C	DTMIN=0.2*DTNAT	HYDRO	38
C	NCYCS=1	HYDRO	39
C	80 CONTINUE	HYDRO	40
C	82 CONTINUE	HYDRO	41
C		HYDRO	42
C	OUTER HYDRO LOOP	HYDRO	43
C	DO 1000 NN=1,NCYCS	HYDRO	44
C	TIME=TIME+DTNH	HYDRO	45
C		HYDRO	46

SUBROUTINE HYDRO (Continued)

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ISPALL = 0
FAC=FLOAT(MINO(N-1,20))/20.
LL=0
DO 900 J=JINIT,JFIN
C      CHECK FOR THE APPROPRIATE PATH
10  XOLD=X(J) $ UOLD=U(J)
    IF (H(J,2) .EQ. NORMAL) GO TO 100
    IF (H(J,2) .EQ. LINTER) GO TO 900
    IF (H(J,2) .EQ. RINTER) GO TO 200
    IF (H(J,2) .EQ. SPALL ) GO TO 300
    IF (H(J,2) .EQ. MIRROR) GO TO 500
    IF (H(J,2) .EQ. PRESS ) GO TO 600
    IF (H(J,2) .EQ. INF ) GO TO 700
C
C*****      NORMAL PATH WITHIN A MATERIAL      **
C
100  IF (NSPEC.GT.0 .OR. ABS(U(J)-U(J+1)).GT.0.001 .OR. EHL(J).GT.1.
1  .OR. ABS(RHLAST).GT.1. .OR. NPR(M).EQ.1) GO TO 102
101  UH=U(J) $ RH=RHL(J) $ XH=.5*(X(J+1)+X(J)+DTNH*U(J))
    DH=DHL(J) $ EH=EHL(J)
    X(J)=X(J)+DTNH*U(J) $ GO TO 800
102  CALL HAFSTEP
C      VELOCITY CALCULATION
120  IF (NALPHA-2) 125,130,135
C      PLANAR CASE
125  U(J)=UOLD-2.*DTNH*(RH-RHLAST)/(ZHL(J-1)+ZHL(J))
    GO TO 140
C      CYLINDRICAL CASE
130  XBAR1=SQRT((X(J-1)**2+X(J)**2)/2.)
    XBAR2=SQRT((X(J)**2+X(J+1)**2)/2.)
    U(J)=U(J)+4.*DTNH*(RHLAST*XBAR1-RH*XBAR2+(PHL(J-1)+SDT(J-1))*
1  (X(J)-XBAR1)+(PHL(J)+SDT(J))*(XBAR2-X(J)))/(ZHL(J)+ZHL(J-1))
    GO TO 140
C      SPHERICAL CASE
135  XBAR1 = ((X(J-1)**3+X(J)**3)/2.)*(1./3.)
    XBAR2 = ((X(J)**3+X(J+1)**3)/2.)*(1./3.)
    U(J) = UOLD-2.*DTNH*(RH*XBAR2**2-RHLAST*XBAR1**2+0.5*(SHL(J-1)-3.*
1  PHL(J-1))*(XBAR1+X(J))*(X(J)-XBAR1)+0.5*(SHL(J)-3.*PHL(J))
1  *(XBAR2+X(J))*(XBAR2-X(J)))/(ZHL(J-1)+ZHL(J))*3.
C      COORDINATE CALCULATION
140  X(J)=X(J)+0.5*DTNH*(U(J)+UOLD)
    DT=(X(J+1)+U(J+1)*DTNH-X(J))/CEF
    GO TO 800
C
C*****      INTERFACE      **
C
C      LEFT VALUES ARE IN (J-1) CELLS AND RIGHT VALUES ARE IN (J) CELLS
200  IF (X(J-1) .LT. X(J)) GO TO 300
    MLAST=M $ LL=LL+1 $ M=JMAT(LL)
    CALL HAFSTEP
C      CHECK STRESS AND SET INDICATORS FOR SPALL
    J1=J-1
    IF (R(LL) .GT. T(J1)) GO TO 205
    H(J,2)=SPALL $ R(LL)=T(J1)=0. $ ISPALL=ISPALL+1
    IF (MAXPR(9) .LE. 0) GO TO 205
    PRINT 5230, N,NN,LL,TIME
205  J1=J-1 $ J2=J-2
    UOLD=U(J1)
    IF (NALPHA-2) 210,212,215
C      PLANAR CASE
210  U(J)=(U(J1)*ZHL(J2)+U(J)*ZHL(J)-2.*DTNH*(RH-RHLAST))/
1  (ZHL(J)+ZHL(J2))
    GO TO 218
C      CYLINDRICAL CASE
212  XBAR1=SQRT((X(J2)**2+X(J)**2)/2.)
    XBAR2=SQRT((X(J)**2+X(J+1)**2)/2.)
    U(J)=(U(J1)*ZHL(J2)+U(J)*ZHL(J)+4.*DTNH*(RHLAST*XBAR1-RH*XBAR2+
1  (PHL(J2)+SDT(J2))*(X(J)-XBAR1)+(PHL(J)+SDT(J))*(XBAR2-X(J)))/
2  (ZHL(J)+ZHL(J2))
    GO TO 218
C      SPHERICAL CASE
215  XBAR1 = ((X(J2)**3+X(J)**3)/2.)*(1./3.)
    XBAR2 = ((X(J)**3+X(J+1)**3)/2.)*(1./3.)
    U(J) = (U(J1)*ZHL(J2)/3.+U(J)*ZHL(J)/3.-2.*DTNH
1  *(RH*XBAR2**2-RHLAST*XBAR1**2+0.5*(SHL(J2)-3.*PHL(J2))*
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HYDRO 48
HYDRO 49
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HYDRO 120
HYDRO 121

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SUBROUTINE HYDRO (Continued)

2	(XBAR1+X(J))*(X(J)-XBAR1)+0.5*(SHL(J)-3.*PHL(J))*(XBAR2+X(J))	HYDR0	122
3	*(XBAR2-X(J)))/(ZHL(J)+ZHL(J2))*3.	HYDR0	123
218	U(J)=U(J)	HYDR0	124
	X(J)=X(J1)=X(J)+.5*DTNH*(U(J)+UOLD)	HYDR0	125
	R(LL)=(RH*ZHL(J2)+RHLAST*ZHL(J)+D.5*(ULOLD-UOLD)*ZHL(J2)*	HYDR0	126
1	ZHL(J)/DTNH)/(ZHL(J)+ZHL(J2))	HYDR0	127
	DT=(X(J+1)+U(J+1)*DTNH-X(J))/CEF	HYDR0	128
22D	CONTINUE	HYDR0	129
	G0 TO 8DD	HYDR0	130
C		HYDR0	131
C*****	INTERFACE SPALL	** HYDR0	132
C		HYDR0	133
30D	IF (J.EQ. JINIT) G0 TO 330	HYDR0	134
	MLAST=M	HYDR0	135
C	LEFT SIDE	HYDR0	136
	J1=J-1	HYDR0	137
	XLOLD=X(J-1) \$ ULOLD=U(J-1)	HYDR0	138
	IF (NALPHA-2) 305,310,315	HYDR0	139
C	PLANAR CASE	HYDR0	140
305	U(J-1)=ULOLD+2.*DTNH*RHLAST/ZHL(J-2)	HYDR0	141
	G0 TO 320	HYDR0	142
C	CYLINDRICAL CASE	HYDR0	143
310	XBAR1=SQRT((X(J-2)**2+X(J-1)**2)/2.)	HYDR0	144
	U(J-1)=U(J-1)+4.*DTNH*(RHLAST*XBAR1+(PHL(J-2)+SDT(J-2))*	HYDR0	145
1	(X(J-1)-XBAR1))/(ZHL(J-2))	HYDR0	146
	G0 TO 320	HYDR0	147
C	SPHERICAL CASE	HYDR0	148
315	XBAR1 = ((X(J-2)**3+X(J-1)**3)/2.)*(1./3.)	HYDR0	149
	U(J-1) = ULOLD+2.*DTNH*(RHLAST*XBAR1**2-D.5*(SHL(J-2)-3.*PHL(J-2)	HYDR0	150
1	)*(XBAR1+X(J-1))*(X(J-1)-XBAR1))/ZHL(J-2)*3.	HYDR0	151
320	X(J-1)=XLOLD+0.5*DTNH*(U(J-1)+ULOLD)	HYDR0	152
	DT=1.	HYDR0	153
	IF (J.EQ. JFIN) G0 TO 9DD	HYDR0	154
C	RIGHT SIDE	HYDR0	155
330	LL=LL+1 \$ M=JMAT(LL)	HYDR0	156
	R(LL)=0.	HYDR0	157
	IF (NSPEC.GT.0 .OR. ABS(U(J)-U(J+1)).GT.0.001 .OR. EHL(J).GT.1.	HYDR0	158
1	.OR. ABS(RHLAST).GT.1. .OR. NPR(M).EQ.1) G0 TO 332	HYDR0	159
331	UH=U(J) \$ RH=RHL(J) \$ XH=.5*(X(J+1)+X(J)+DTNH*U(J))	HYDR0	160
	X(J)=X(J)+DTNH*U(J) \$ DT=1.	HYDR0	161
	IF (NALPHA.GT.1 .AND. J.EQ. JINIT) X(J)=AMAX1(XOLD,D.)	HYDR0	162
	IF (NALPHA.GT.1 .AND. J.EQ. JINIT .AND. X(J).EQ.D.) U(J)=D.	HYDR0	163
	DH=DHL(J) \$ EH=EHL(J)	HYDR0	164
	IF (J.EQ. JINIT) 80D,335	HYDR0	165
332	CALL HAFSTEP	HYDR0	166
	IF (RHL(J).GT. T(J)) G0 TO 334	HYDR0	167
	RH=RHL(J)=SHL(J)=PHL(J)=T(J)=0.	HYDR0	168
334	UOLD=U(J) \$ XOLD=X(J)	HYDR0	169
	IF (NALPHA - 2) 3341,3342,3343	HYDR0	170
C	PLANAR CASE	HYDR0	171
3341	U(J)=UOLD-2.*DTNH*RH/ZHL(J)	HYDR0	172
	G0 TO 3344	HYDR0	173
C	CYLINDRICAL CASE	HYDR0	174
3342	XBAR2=SQRT((X(J)**2+X(J+1)**2)/2.)	HYDR0	175
	U(J)=UOLD+4.*DTNH*(-RH*XBAR2+(PHL(J)+SDT(J))*(XBAR2-X(J)))/ZHL(J)	HYDR0	176
	G0 TO 3344	HYDR0	177
C	SPHERICAL CASE	HYDR0	178
3343	XBAR2 = ((X(J)**3+X(J+1)**3)/2.)*(1./3.)	HYDR0	179
	U(J) = UOLD-2.*DTNH*(RH*XBAR2**2+0.5*(SHL(J)-3.*PHL(J))*	HYDR0	180
1	(XBAR2+X(J))*(XBAR2-X(J))/ZHL(J)*3.	HYDR0	181
3344	X(J)=XOLD+D.5*DTNH*(U(J)+UOLD)	HYDR0	182
	IF (NALPHA.GT.1 .AND. J.EQ. JINIT) X(J)=AMAX1(XOLD,0.)	HYDR0	183
	IF (NALPHA.GT.1 .AND. J.EQ. JINIT .AND. X(J).EQ.D.) U(J)=0.	HYDR0	184
	DT=(X(J+1)+U(J+1)*DTNH-X(J))/CEF	HYDR0	185
C	CHECK FOR RECOMBINATION	HYDR0	186
	IF (J.EQ. JINIT) G0 TO 8DD	HYDR0	187
335	IF (X(J).LE. X(J-1)) G0 TO 365	HYDR0	188
	ISPALL=ISPALL+1 \$ G0 TO 8DD	HYDR0	189
C	RESET ARRAY VARIABLES AND G0 TO INTERFACE ROUTE	HYDR0	190
365	H(J,2)=RINTER \$ X(J)=XOLD \$ X(J-1)=XLOLD \$ U(J)=UOLD	HYDR0	191
	PRINT 1365,N,J,TIME	HYDR0	192
	U(J-1)=ULOLD	HYDR0	193
	DT=D.1*AMIN1(DT,DTP)	HYDR0	194
	IF (DT.LT. 0.) DT=1.	HYDR0	195
	IF (DT.GT. DTMIN) G0 TO 205	HYDR0	196

SUBROUTINE HYDRO (Continued)

<pre> C DTMIN=DT \$ JTS=J \$ GO TO 205 C***** MIRROR AT FRONT SURFACE C 500 LL=LL+1 \$ M=JMAT(LL) IF (J .GE. JFIN-1) GO TO 800 CALL HAFSTEP R(LL)=RHL(J) X(J)=X(J)+DTNH*U(J) DT=(X(J+1)+DTNH*U(J+1)-X(J))/CEF IF (R(LL) .GT. T(JFIN-1)) GO TO 800 H(J,2)=SPALL R(LL)=T(JFIN-1)=0. GO TO 800 C C***** PRESSURE BOUNDARY AT FRONT SURFACE C 600 LL=LL+1 IF (J .EQ. JFIN) GO TO 650 M=JMAT(LL) IF (T6(1) .EQ. 0.) GO TO 602 R(LL)=P6(1)*EXP((TIME-DTNH)/T6(1)) CALL HAFSTEP RHAF=P6(1)*EXP((TIME-0.5*DTNH)/T6(1)) GO TO 603 602 R(LL)=SIGMAT(1,TIME-DTNH) CALL HAFSTEP RHAF=SIGMAT(1,TIME-0.5*DTNH) 603 CONTINUE IF (NALPHA-2) 605,610,615 C PLANAR CASE 605 U(J)=UOLD-2.*(RH-RHAF)/ZHL(J)*DTNH GO TO 620 C CYLINDRICAL CASE 610 XBAR2=SQRT((X(J)**2+X(J+1)**2)/2.) U(J)=U(J)+4.*DTNH*(RHAF*X(J)-RH*XBAR2+(PHL(J)+SDT(J))*(XBAR2-X(J)) 1)/ZHL(J) GO TO 620 C SPHERICAL CASE 615 XBAR2=((X(J)**3+X(J+1)**3)/2.)*(1./3.) U(J)=U(J)+2.*DTNH*(RHAF*X(J)**2-RH*XBAR2**2+0.5*(SHL(J)-3.*PHL(J)) 1 *(XBAR2+X(J))*(XBAR2-X(J)))/ZHL(J)*3. 620 X(J)=X(J)+0.5*DTNH*(U(J)+UOLD) DT=(X(J+1)+DTNH*U(J+1)-X(J))/CEF GO TO 800 C C***** PRESSURE BOUNDARY AT OUTER SURFACE C 650 IF (T6(2) .EQ. 0.) GO TO 652 R(LL)=P6(2)*EXP((TIME-DTNH)/T6(2)) RHAF=P6(2)*EXP((TIME-0.5*DTNH)/T6(2)) GO TO 654 652 R(LL)=SIGMAT(2,TIME-DTNH) RHAF=SIGMAT(2,TIME-0.5*DTNH) 654 CONTINUE UOLD=U(J-1) IF (NALPHA-2) 660,665,670 C PLANAR CASE 660 U(J-1)=UOLD+2.*(RHLAST-RHAF)/ZHL(J-2)*DTNH GO TO 675 C CYLINDRICAL CASE 665 XBAR1=SQRT((X(J-2)**2+X(J-1)**2)/2.) U(J-1)=U(J-1)+4.*DTNH*(RHLAST*XBAR1-RHAF*X(J-1)+(PHL(J-2)+SDT(J-2)) 1 *(X(J-1)-XBAR1))/ZHL(J-2) GO TO 675 C SPHERICAL CASE 670 XBAR1=((X(J-2)**3+X(J-1)**3)/2.)*(1./3.) U(J-1)=U(J-1)+2.*DTNH*(RHLAST*XBAR1**2-RHAF*X(J-1)**2+0.5*(SHL(J-2) 1 -3.*PHL(J-2))*(XBAR1+X(J-1))*(XBAR1-X(J-1)))/ZHL(J-2)*3. 675 X(J)=X(J-1)+0.5*DTNH*(U(J-1)+UOLD) U(J)=U(J-1) \$ DT=(X(J-1)+U(J-1)*DTNH-X(J-2))/CHL(J-2) GO TO 800 C C***** INFINITE BOUNDARY AT FRONT SURFACE. C </pre>	<pre> HYDRO 197 HYDRO 198 HYDRO 199 HYDRO 200 HYDRO 201 HYDRO 202 HYDRO 203 HYDRO 204 HYDRO 205 HYDRO 206 HYDRO 207 HYDRO 208 HYDRO 209 HYDRO 210 HYDRO 211 ** HYDRO 212 HYDRO 213 HYDRO 214 HYDRO 215 HYDRO 216 HYDRO 217 HYDRO 218 HYDRO 219 HYDRO 220 HYDRO 221 HYDRO 222 HYDRO 223 HYDRO 224 HYDRO 225 HYDRO 226 HYDRO 227 HYDRO 228 HYDRO 229 HYDRO 230 HYDRO 231 HYDRO 232 HYDRO 233 HYDRO 234 HYDRO 235 HYDRO 236 HYDRO 237 HYDRO 238 HYDRO 239 HYDRO 240 HYDRO 241 HYDRO 242 HYDRO 243 HYDRO 244 HYDRO 245 HYDRO 246 HYDRO 247 HYDRO 248 HYDRO 249 HYDRO 250 HYDRO 251 HYDRO 252 HYDRO 253 HYDRO 254 HYDRO 255 HYDRO 256 HYDRO 257 HYDRO 258 HYDRO 259 HYDRO 260 HYDRO 261 HYDRO 262 HYDRO 263 HYDRO 264 HYDRO 265 HYDRO 266 HYDRO 267 HYDRO 268 HYDRO 269 HYDRO 270 HYDRO 271 </pre>
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SUBROUTINE HYDRO (Concluded)

700	IF (J .EQ. JFIN) GO TO 720	HYDR0	272
	LL=LL+1 \$ M=JMAT(LL)	HYDR0	273
	IF (ABS(U(J)-U(J+1)) .LT. .001 .AND. EHL(J) .LT. 1. .AND.	HYDR0	274
1	NPR(M) .NE. 1) GO TO 101	HYDR0	275
	DS=SQRT(RHOS(M)*(EQSTC(M)+1.333*MU(M)))*(U(JFIN+1)-UOLD)	HYDR0	276
	DP=EQSTC(M)/(EQSTC(M)+1.333*MU(M))*DS	HYDR0	277
	SDH=SHL(JFIN+1)-PHL(JFIN+1)+DS-DP	HYDR0	278
	PHL(JFIN+1)=PHL(JFIN+1)+DP	HYDR0	279
	U(JFIN+1)=UOLD	HYDR0	280
	IF (ABS(SDH) .GT. 0.6667* YHL(J)) SDH=SIGN(0.6667*YHL(J),SDH)	HYDR0	281
	SHL(JFIN+1)=RHLAST=SDH+PHL(JFIN+1)	HYDR0	282
	R(LL)=RHLAST	HYDR0	283
	GO TO 100	HYDR0	284
C		HYDR0	285
C*****	INFINITE BOUNDARY AT REAR SURFACE.	HYDR0	286
C		HYDR0	287
720	LL=LL+1	HYDR0	288
	DS=SQRT(RHOS(M)*(EQSTC(M)+1.333*MU(M)))*(U(J-1)-U(J))	HYDR0	289
	DP=EQSTC(M)/(EQSTC(M)+1.333*MU(M))*DS	HYDR0	290
	SDH=SHL(J-1)-PHL(J-1)+DS-DP	HYDR0	291
	PHL(J-1)=PHL(J-1)+DP	HYDR0	292
	UOLD=U(J)=U(J-1)	HYDR0	293
	IF (ABS(SDH) .GT. 0.6667* YHL(J-1))SDH=SIGN(0.6667*YHL(J-1),SDH)	HYDR0	294
	SHL(J-1)=RH=RHL(J-1)=SDH+PHL(J-1)	HYDR0	295
	R(LL)=RH	HYDR0	296
	U(J-1)=UOLD-DTNH*(RH-RHLAST)/ZHL(J-2)	HYDR0	297
	X(J-1)=X(J-1)+0.5*DTNH*(UOLD+U(J-1))	HYDR0	298
C		HYDR0	299
C*****	END OF HYDRO PATHS	HYDR0	300
C		HYDR0	301
C		HYDR0	302
800	CONTINUE	HYDR0	303
	IF (LSUB(7) .EQ. 1) RETURN	HYDR0	304
C*****	END OF CYCLE RESET	HYDR0	305
	XLAST=XOLD \$ ULAST=UOLD	HYDR0	306
	XHLAST=XH \$ UHLAST=UH \$ RHLAST=RH \$ DHLAST=DH	HYDR0	307
	EHLAST=EH \$ SHLAST=SH	HYDR0	308
C		HYDR0	309
C	SMAX CALCULATION	HYDR0	310
	IF (SHL(J) .GT. SMAX) 820,822	HYDR0	311
820	SMAX=SHL(J) \$ JSMAX=J	HYDR0	312
C		HYDR0	313
C	TIME STEP CALCULATION	HYDR0	314
822	IF (DT .LT. 0.) DT=1.	HYDR0	315
	IF (DT .GT. DTMIN) GO TO 826	HYDR0	316
824	DTMIN=DT \$ JTS=J	HYDR0	317
826	DTP=DT	HYDR0	318
C		HYDR0	319
C	JSTAR CALCULATION	HYDR0	320
850	IF (ABS(U(J)) .LT. 1.E-3 .AND. EHL(J) .LT. 1.) 851,900	HYDR0	321
851	IF (J .GT. JSTAR) 852,900	HYDR0	322
852	JSTAR=J-1	HYDR0	323
	GO TO 990	HYDR0	324
C	END OF HYDRO INNER LOOP	HYDR0	325
900	CONTINUE	HYDR0	326
	JSTAR=JFIN-1	HYDR0	327
990	DTN=DTNH	HYDR0	328
	JTS=JTS+1000*ISPALL	HYDR0	329
C	END OF HYDRO OUTER LOOP	HYDR0	330
1000	CONTINUE	HYDR0	331
1002	RETURN	HYDR0	332
1365	FORMAT(* RECOMBINATION AT CYCLE *14,*, J=*14,*, TIME=*1PE10.3)	HYDR0	333
5115	FORMAT (* SPALL AT N, NN=*214,* FOR J=*14,*, NSPALL=*14,*, TIME=*1PE10.3)	HYDR0	334
1	1PE10.3)	HYDR0	335
5230	FORMAT (* INTERFACE SPALL AT N, NN =*214,* ON LEFT OF LAYER *12,	HYDR0	336
1	*, TIME=*1PE10.3)	HYDR0	337
	END	HYDR0	338

SUBROUTINE HYPO

C	SUBROUTINE HYPO(1NDE,1N,M,CJ,DH,EMU,EMUD,EPS,EPS0,J,P,SDH)	HYP0	2
C		HYP0	3
C	THIRD VERSION OF VARIABLE MODULUS MODEL INCLUDING AN INTEGRAL	HYP0	4
C	DEFINITION OF LOADING SURFACES FOR P AND SDH AND DIFFERENTIAL	HYP0	5
C	RELATIONS ONLY FOR UNLOADING	HYP0	6
C		HYP0	7
C	ROUTINE IS WRITTEN FOR 1-DIMENSIONAL PLANAR AND SPHERICAL FLOW.	HYP0	8
C	FOR 1-D CYLINDRICAL FLOW,SDH IS INTERPRETED AS 2/3x EFFECTIVE	HYP0	9
C	STRESS AND RADIAL AND TANGENTIAL DEVIATOR STRESSES ARE COMPUTED	HYP0	10
C	FROM SDH IN HSTRESS.	HYP0	11
C		HYP0	12
C	SUBROUTINE COMPUTES PRESSURE P AND DEVIATOR STRESS SDH AND	HYP0	13
C	SOUND SPEED CJ.	HYP0	14
C		HYP0	15
C	SUBROUTINE IS CALLED TWICE	HYP0	16
C	INDE=0 CALLED FROM GENRAT	HYP0	17
C	READ MATERIAL PROPERTY DATA AND INITIALIZE VARIABLES	HYP0	18
C	INDE=1 CALLED FROM HSTRESS	HYP0	19
C	COMPUTE PRESSURE, DEVIATOR STRESS, AND SOUND SPEED.	HYP0	20
C	REAL K0,K1,K2,KOUN,K1UN,K2UN,KY	HYP0	21
C	DIMENSION G0(6),G1(6),G2(6),GU(6),K0(6),K1(6),K2(6),KOUN(6),	HYP0	22
C	K1UN(6),K2UN(6),KY(6),EMUY(6)	HYP0	23
C	IF(1NDE.GT.0)GO TO 200	HYP0	24
C		HYP0	25
C	***READ AND INITIALIZE***	HYP0	26
C		HYP0	27
C	READ(1N,1000)A1,G0(M),G1(M),G2(M),GU(M),KY(M),EMUY(M)	HYP0	28
C	WRITE(6,1000)A1,G0(M),G1(M),G2(M),GU(M),KY(M),EMUY(M)	HYP0	29
C	READ(1N,1000)A1,K0(M),K1(M),K2(M),KOUN(M),K1UN(M),K2UN(M)	HYP0	30
C	WRITE(6,1000)A1,K0(M),K1(M),K2(M),KOUN(M),K1UN(M),K2UN(M)	HYP0	31
C	G0(M)=1.333*G0(M)	HYP0	32
C	G1(M)=1.333*G1(M)	HYP0	33
C	G2(M)=0.667*G2(M)	HYP0	34
C	GU(M)=1.333*GU(M)	HYP0	35
C	K2(M)=0.5*K2(M)	HYP0	36
C	K1UN(M)=0.5*K1UN(M)	HYP0	37
C	K2UN(M)=0.5*K2UN(M)	HYP0	38
C	RETURN	HYP0	39
C		HYP0	40
C	***COMPUTATION OF STRESS***	HYP0	41
C		HYP0	42
200	DMU=EMU-EMU0	HYP0	43
C	DEPS=EPS-EPSP	HYP0	44
C	DEVIATOR STRESS	HYP0	45
C	SDH=AMIN1(SDH+GU(M)*DEPS,EPS*(G0(M)+G1(M)*EMU+G2(M)*EPS))	HYP0	46
C	PRESSURE	HYP0	47
C	IF(EMU.LT.EMUY(M))GO TO 220	HYP0	48
C	BULK=KOUN(M)+K1UN(M)*(EMU+EMU0)+K2UN(M)*(EPS+EPS0)	HYP0	49
C	P=AMIN1(P+DMU*BULK,KY(M)*EMUY(M)+EMU*(K0(M)+K1(M)*EMU+K2(M)*EPS))	HYP0	50
C	GO TO 300	HYP0	51
220	P=AMIN1(P+DMU*KY(M),KY(M)*EMU)	HYP0	52
C	BULK=KY(M)	HYP0	53
300	EMU0=EMU	HYP0	54
C	EPS0=EPS	HYP0	55
C	SOUND SPEED	HYP0	56
C	CJ=SQ RT((BULK+GU(M))/DH)	HYP0	57
C	RETURN	HYP0	58
1000	FORMAT(A10,1P7E10.3)	HYP0	59
C	END	HYP0	60

SUBROUTINE PEST (Continued)

	D0 53 I=1,72	PEST	77
53	RHOP(I)=0.	PEST	78
	D0 54 I=1,96	PEST	79
54	TER(I)=0.	PEST	80
	MP=0 \$ DPDDJ=DPDEJ=0. \$ LS=1 \$ CJ=1.	PEST	81
8	MP=MP+1	PEST	82
	NPM(M) = MP	PEST	83
C		C PEST	84
C	*****	C PEST	85
C	READING OF INPUT DATA	C PEST	86
C	*****	C PEST	87
C		C PEST	88
C	*** READ DATA USED BY ALL MODELS.	*** C PEST	89
	READ(IN,935)A1,KCS(MP),KTS(MP),KRS(MP),A2,KCD(MP),KTD(MP)	PEST	90
1	,KRD(MP)	PEST	91
	WRITE(6,935)A1,KCS(MP),KTS(MP),KRS(MP),A2,KCD(MP),KTD(MP)	PEST	92
1	,KRD(MP)	PEST	93
	WRITE(6,960)IDD,IN,JQ1	PEST	94
C		C PEST	95
	READ(IN,919)A1,AK(MP),A2,MUP(MP),A3,YZER0,A4,RHOP(MP,6,1)	PEST	96
	WRITE(6,920)A1,AK(MP),A2,MUP(MP),A3,YZER0,A4,RHOP(MP,6,1)	PEST	97
	WRITE(6,960)IDD,IN,JQ1	PEST	98
	ALF0=RHOS/RHOP(MP,6,1)	PEST	99
	IF(AK(MP).GT. 0. .AND. AK(MP).LE. EQSTCM*RHOP(MP,6,1)	PEST	100
1	/RHOS) GO TO 20	PEST	101
	IF (AK(MP).GT. 0.) GO TO 10	PEST	102
C *	IF AK IS NEGATIVE, IT IS INTERPRETED AS THE SHEAR MODULUS	* C PEST	103
C *	OF THE SOLID.	* C PEST	104
	GS = -AK(MP)	PEST	105
	AK(MP) = EQSTCM/(ALF0+0.75*EQSTCM/GS*(ALF0-1.))	PEST	106
	MUP(MP) = GS*(1.-5.*(1.-1./ALF0)*(3.*EQSTCM+4.*GS)/(9.*EQSTCM	PEST	107
1	+8.*GS))	PEST	108
	GO TO 15	PEST	109
C *	IF AK IS TOO LARGE, IT IS REDUCED TO THE MAXIMUM PERMITTED.	* C PEST	110
10	AK(MP)=EQSTCM*RHOP(MP,6,1)/RHOS	PEST	111
15	WRITE(6,950) AK(MP), MUP(MP)	PEST	112
	WRITE(6,960)IDD,OUT,JQ1	PEST	113
20	YADDM=0.666667*YZER0 \$ MUP(MP)=1.333333*MUP(MP)	PEST	114
	C=SQR((AK(MP)+AMAX1(0.,MUP(MP)))/AMIN1(D,RHOP(MP,6,1)))	PEST	115
	J2=5HCOMP, \$ J3=J4=1H	PEST	116
	N=1	PEST	117
	KCSM=KCS(MP) \$ KCDM=KCD(MP) \$ KTSM=KTS(MP) \$ KTD=KTD(MP)	PEST	118
	KRSM=KRS(MP) \$ KRDM=KRD(MP)	PEST	119
	IF (KTSM.EQ. 0) J3=5HTENS, \$ IF (KRSM.EQ. 0) J4=5HRECOM	PEST	120
C		C PEST	121
C	*** READ FOR RATE-INDEPENDENT COMPRESSIVE MODEL.	*** C PEST	122
C		C PEST	123
	GO TO (490,510,520,530,540,550)KCSM	PEST	124
490	CONTINUE	PEST	125
C		C PEST	126
C **	READ AND INITIALIZE FOR POREQST.	** C PEST	127
	READ(IN,939)A1,NREG(MP)	PEST	128
	WRITE(6,940)A1,NREG(MP)	PEST	129
	WRITE(6,960)IDD,IN,JQ2,IDD,JQS,J2,J3,J4	PEST	130
	READ(IN,909)A1,(RHOP(MP,I,N),I=1,5)	PEST	131
	WRITE(6,910)A1,(RHOP(MP,I,N),I=1,5)	PEST	132
	WRITE(6,960)IDD,IN,JQ2	PEST	133
	D0 498 I=1,5	PEST	134
	COSQ(MP,I,N) = 4.0	PEST	135
498	C1(MP,I,N) = 0.15	PEST	136
501	READ(IN,905)(TEMP(I),I=1,8)	PEST	137
	DECODE (3,915,TEMP) A1,A2	PEST	138
	IF (A1.EQ. 1HC .AND. (A2.EQ. 1H0 .OR. A2.EQ. 1H0)) GO TO 502	PEST	139
	IF (A1.EQ. 1HC .AND. A2.EQ. 1H1) GO TO 503	PEST	140
	GO TO 504	PEST	141
502	DECODE (80,910,TEMP)A1,(COSQ(MP,I,N),I=1,5)	PEST	142
	WRITE(6,910)A1,(COSQ(MP,I,N),I=1,5)	PEST	143
	WRITE(6,960)IDD,IN,JQ2	PEST	144
	GO TO 501	PEST	145
503	DECODE (80,910,TEMP)A1,(C1(MP,I,N),I=1,5)	PEST	146
	WRITE(6,910)A1,(C1(MP,I,N),I=1,5)	PEST	147
	WRITE(6,960)IDD,IN,JQ2	PEST	148
	GO TO 501	PEST	149
504	CZJ = COSQ(MP,5,1)	PEST	150
	CWJ = C1(MP,5,1)	PEST	151

SUBROUTINE PEST (Continued)

NP=NREG(MP)	PEST	152
DECODE (80,920,TEMP)A1,P1	PEST	153
WRITE(6,920)A1,P1	PEST	154
WRITE(6,960)IDD,IN,JQ2	PEST	155
PORA(MP,1,N) = P1 \$ PORB(MP,1,N) = PORC(MP,1,N) = 0.	PEST	156
DO 505 NQ=1,NP	PEST	157
READ(IN,919)A1,P2,A2,DELP,A3,YADDP(MP,NQ,N)	PEST	158
WRITE(6,920)A1,P2,A2,DELP,A3,YADDP(MP,NQ,N)	PEST	159
WRITE(6,960)IDD,IN,JQ2	PEST	160
IF (NQ.NE. NP) GO TO 5045	PEST	161
IF (RHOP(MP,NP+1,N).GT. RHOS) GO TO 5045	PEST	162
RHOP(MP,NP+1,N) = RHOS*(1.+TSQE(0,P2,0.,EQSTCM,EQSTDM,EQSTSM,	PEST	163
1 EQSTGM,EQSTHM,EQSTEM,RHOS,EQSTNM,0.,EQSTVM,EQSTAM,NCYC))	PEST	164
WRITE(6,932)RHOP(MP,NP+1,N)	PEST	165
WRITE(6,960)IDD,OUT,JQ2	PEST	166
5045 DRHO=RHOP(MP,NQ+1,N)-RHOP(MP,NQ,N)	PEST	167
AA=P2-P1-4.*DELP*RHOP(MP,NQ,N)/DRHO	PEST	168
PORA(MP,NQ+1,N)=P1+RHOP(MP,NQ+1,N)/DRHO*AA	PEST	169
BB=P2-P1-4.*DELP*(RHOP(MP,NQ+1,N)+RHOP(MP,NQ,N))/DRHO	PEST	170
PORB(MP,NQ+1,N)=-RHOP(MP,NQ+1,N)*RHOP(MP,NQ,N)/DRHO*BB	PEST	171
PORC(MP,NQ+1,N)=-4.*DELP*(RHOP(MP,NQ+1,N)*RHOP(MP,NQ,N)/DRHO)**2	PEST	172
YADDP(MP,NQ,N) = YADDP(MP,NQ,N)/DRHO	PEST	173
505 P1=P2	PEST	174
YADDP(MP,NP+1,N) = 0.	PEST	175
RHOP(MP,5,N) = RHOP(MP,NP+1,N)	PEST	176
GO TO 600	PEST	177
510 CONTINUE	PEST	178
C	C	PEST 179
C ** READ AND INITIALIZE FOR PORHOLT.	** C	PEST 180
READ(IN,919)A1,RHOP(MP,1,N)		PEST 181
WRITE(6,920)A1,RHOP(MP,1,N)		PEST 182
READ(IN,919)A1,RHOP(MP,5,N),A2,DPDRHO,A3,PY,A4,YADDP(MP,1,N)		PEST 183
WRITE(6,920)A1,RHOP(MP,5,N),A2,DPDRHO,A3,PY,A4,YADDP(MP,1,N)		PEST 184
WRITE(6,960)IDD,IN,JQ15,IDD,JQS,J2,J3,J4		PEST 185
IF (RHOP(MP,5,N).LT. 100.) GO TO 512		PEST 186
P2 = RHOP(MP,5,N)		PEST 187
RHOP(MP,5,N)=RHOS*(1.+TSQE(0,P2,0.,EQSTCM,EQSTDM,EQSTSM,EQSTGM,		PEST 188
1 EQSTHM,EQSTEM,RHOS,EQSTNM,0.,EQSTVM,EQSTAM,NCYC))		PEST 189
WRITE(6,932)RHOP(MP,5,N)		PEST 190
WRITE(6,960)IDD,OUT,JQ15		PEST 191
512 RHOP(MP,2,N)=RHOP(MP,1,N)*(PY/AK(MP)+1.)		PEST 192
RHOP(MP,3,N)=RHOS/(1.-RHOS*PY/RHOP(MP,2,N)/EQSTCM)		PEST 193
ALFE=RHOP(MP,3,N)/RHOP(MP,2,N)		PEST 194
R=RHOP(MP,3,N)-RHOS		PEST 195
PORA(MP,1,N)=ALFE*(ALFE*RHOP(MP,2,N)/EQSTCM*DPDRHO-R/RHOS)		PEST 196
R1=PORA(MP,1,N)/(RHOP(MP,5,N)-RHOP(MP,2,N))		PEST 197
PORB(MP,1,N)=(RHOP(MP,5,N)-RHOP(MP,3,N))/		PEST 198
1 (RHOP(MP,5,N)-RHOP(MP,2,N))**2-R1		PEST 199
YADDP(MP,1,N) = YADDP(MP,1,N)/(RHOP(MP,5,N)-RHOP(MP,2,N))		PEST 200
WRITE(6,930)		PEST 201
IF (N.GE. 2) GO TO 640		PEST 202
GO TO 600		PEST 203
520 CONTINUE		PEST 204
C	C	PEST 205
C ** READ AND INITIALIZE FOR CARROLL-HOLT.	** C	PEST 206
READ(IN,919)A1,YCH,A3,EPS(MP,N),A4,TER(MP,7,N)		PEST 207
WRITE(6,920)A1,RHOP(MP,1,N),A2,YCH,A3,EPS(MP,N),A4,TER(MP,7,N)		PEST 208
WRITE(6,960)IDD,IN,JQ3,JQ4,JQS,J2,J3,J4		PEST 209
IF (A1.EQ. 10H YCH =) GO TO 525		PEST 210
PY = YCH		PEST 211
IF (ABS(EPS(MP,N)).LT. 1.) GO TO 526		PEST 212
P2 = EPS(MP,N)		PEST 213
RV=1.-RHOP(MP,1,N)/RHOS		PEST 214
C * PY AND PC KNOWN	* C	PEST 215
RHOP(MP,5,N)=RHOS*(1.+TSQE(0,P2,0.,EQSTCM,EQSTDM,EQSTSM,EQSTGM,		PEST 216
1 EQSTHM,EQSTEM,RHOS,EQSTNM,0.,EQSTVM,EQSTAM,NCYC))		PEST 217
BB = BBMIN = (RHOP(MP,5,N)/RHOS-1.)*EQSTCM/PY		PEST 218
ALFA = 1./(1.-RV)		PEST 219
DEL(MP,N) = PY/(EQSTCM*ALOG(1.-RHOP(MP,1,1)/RHOS))		PEST 220
IF (YCH.LT. 0.) BBMIN = AMIN1(BB,1./DEL(MP,N))		PEST 221
BBMIN = AMAX1(BBMIN,0.24627*ALFA**2+2.8512*ALFA-1.9633)		PEST 222
IF (BB.GT. BBMIN) GO TO 521		PEST 223
BB = BBMIN		PEST 224
RHOP(MP,5,N) = RHOS*(1.+BB*PY/EQSTCM)		PEST 225
EO = 1./BB		PEST 226

SUBROUTINE PEST (Continued)

	WRITE(6,927)	PEST	227
	GO TO 5215	PEST	228
521	E0 = RV**BB	PEST	229
5215	B0 = ALOG(E0)/ALOG(RV+E0)	PEST	230
	E2= E1 = (RV+E0)**BB	PEST	231
	IF (ABS(E0-E1) .LT. 1.E-05*E1) GO TO 524	PEST	232
	B1 = ALOG(E1)/ALOG(RV+E1)	PEST	233
	NW = 0	PEST	234
522	NW = NW+1	PEST	235
	E2 = E1*EXP((BB-B1)*(ALOG(RV+E1)/(1.-BB*E1/(RV+E1))))	PEST	236
	B2 = ALOG(E2)/ALOG(RV+E2)	PEST	237
	AW = NW	PEST	238
	IF (ABS(B2-B1) .LT. 1.E-5 .OR. AW .GE. 10.) GO TO 524	PEST	239
	E0 = E1 \$ B0 = B1 \$ E1 = E2 \$ B1 = B2	PEST	240
	GO TO 522	PEST	241
524	EPS(MP,N) = E2	PEST	242
	DEL(MP,N) = (1.-RHOP(MP,5,N)/RHOS)/ALOG(EPS(MP,N))	PEST	243
	IF (BB .LE. BBMIN) GO TO 5275	PEST	244
	GO TO 528	PEST	245
C *	YCH AND EPS KNOWN	* C PEST	246
525	DEL(MP,N) = 0.66667*YCH/EQSTCM	PEST	247
	IF (YCH .LT. 0.) EPS(MP,N) = AMAX1(EPS(MP,N),ABS(DEL(MP,N)))	PEST	248
	PY = -0.666667*YCH*ALOG(1.-RHOP(MP,1,N)/RHOS+EPS(MP,N))	PEST	249
	GO TO 527	PEST	250
C *	PY AND EPS KNOWN	* C PEST	251
526	DEL(MP,N) = -PY/EQSTCM/ALOG(1.-RHOP(MP,1,N)/RHOS+EPS(MP,N))	PEST	252
	IF (YCH .LT. 0.) EPS(MP,N) = AMAX1(EPS(MP,N),ABS(DEL(MP,N)))	PEST	253
527	RHOP(MP,5,N) = RHOS*(1.-DEL(MP,N)*ALOG(EPS(MP,N)))	PEST	254
5275	CALL EQST(0.,RHOP(MP,5,N),P2,M,1.,A1,A2)	PEST	255
C *	ALL C-H	* C PEST	256
528	ALE(MP,N) = DEL(MP,N)*ALOG(EPS(MP,N))	PEST	257
	APC(MP,N) = RHOS/RHOP(MP,5,N)	PEST	258
	WRITE(6,925)PY,P2,EPS(MP,N)	PEST	259
	WRITE(6,960)IDD,OUT,JQ3,JQ4	PEST	260
	WRITE(6,932)RHOP(MP,5,N)	PEST	261
	WRITE(6,960)IDD,OUT,JQ3,JQ4	PEST	262
	EPS(MP,N) = 1.+EPS(MP,N)	PEST	263
	GO TO 600	PEST	264
530	CONTINUE	PEST	265
C		C PEST	266
C **	READ INPUT AND INIT FOR HERRMANN P-ALPHA.	** C PEST	267
	READ(IN,919)A1,PC,A3,PY	PEST	268
	WRITE(6,920)A1,RHOP(MP,1,1),A2,PC,A3,PY	PEST	269
	WRITE(6,960)IDD,IN,JQ5,JQ6,JQS,J2,J3,J4	PEST	270
	PORC(MP,1,N) = PY \$ PORC(MP,1,N) = PC	PEST	271
	GO TO 600	PEST	272
540	CONTINUE	PEST	273
C		C PEST	274
C **	READ AND INIT FOR HENDRON.	** C PEST	275
	GO TO 600	PEST	276
550	CONTINUE	PEST	277
C		C PEST	278
C **	READ AND INIT FOR TBS.	** C PEST	279
	GO TO 600	PEST	280
600	IF (N .GE. 2) GO TO 640	PEST	281
	N = 2	PEST	282
	J2=5HTENS \$ J3=J4=1H	PEST	283
C		C PEST	284
C ***	READ FOR RATE-INDEPENDENT TENSION MODEL.	*** C PEST	285
C		C PEST	286
	IF (KTSM .EQ. 0 .AND. KCSM .EQ. 3) GO TO 610	PEST	287
	GO TO (615,620,520) KTSM	PEST	288
C		C PEST	289
C **	REPEAT CARROLL-HOLT ARRAY FOR N=2.	** C PEST	290
610	ALE(MP,2)=-ALE(MP,1) \$ EPS(MP,2)=EPS(MP,1)	PEST	291
	DEL(MP,2)=-DEL(MP,1) \$ TER(MP,7,2) = TER(MP,7,1)	PEST	292
	APC(MP,2)=1./(1.-ALE(MP,N))	PEST	293
	RHOP(MP,5,N)=RHOS/APC(MP,2)	PEST	294
	WRITE(6,932)RHOP(MP,5,N)	PEST	295
	WRITE(6,960)IDD,OUT,JQ3,JQ4,JQS,J2	PEST	296
	GO TO 600	PEST	297
615	CONTINUE	PEST	298
C		C PEST	299
C **	READ AND INIT FOR VARIABLE STRENGTH.	PEST	300
	READ(IN,919)A1,TER(MP,5,N),A2,TER(MP,7,N)	PEST	301

SUBROUTINE PEST (Continued)

	WRITE(6,920)A1,TER(MP,5,N),A2,TER(MP,7,N)	PEST	302
	WRITE(6,960)IDD,IN,JQ7,JQ8,JQS,J2	PEST	303
	GO TO 600	PEST	304
620	CONTINUE	PEST	305
C		C PEST	306
C **	READ AND INIT FOR K1C.	** C PEST	307
	READ(IN,919)A1,K1C(MP),A2,TER(MP,7,N)	PEST	308
	WRITE(6,920)A1,K1C(MP),A2,TER(MP,7,N)	PEST	309
	WRITE(6,960)IDD,IN,JQ9,JQ10,JQS,J2	PEST	310
	GO TO 600	PEST	311
640	CONTINUE	PEST	312
	IF (N .EQ. 3) GO TO 700	PEST	313
	N = 3	PEST	314
	J2=5HRECOM	PEST	315
C		C PEST	316
C ***	READ FOR RATE-INDEPENDENT RECOMPRESSION MODEL.	*** C PEST	317
C		C PEST	318
	IF (KRSM .GT. 0) GO TO 660	PEST	319
C		C PEST	320
C **	REPEAT ARRAYS KRS=KCS.	** C PEST	321
	GO TO (641,645,647,648) KCSM	PEST	322
C		C PEST	323
C **	POREQST.	** C PEST	324
641	NPP = NP+1	PEST	325
	DO 642 NQ = 1,NPP	PEST	326
	PORA(MP,NQ,3)=PORA(MP,NQ,1) \$ YADDP(MP,NQ,3)=YADDP(MP,NQ,1)	PEST	327
	PORB(MP,NQ,3)=PORB(MP,NQ,1) \$ PORC(MP,NQ,3)=PORC(MP,NQ,1)	PEST	328
642	CONTINUE	PEST	329
	DO 644 NQ=1,5	PEST	330
	RHOP(MP,NQ,3)=RHOP(MP,NQ,1) \$ COSQ(MP,NQ,3)=COSQ(MP,NQ,1)	PEST	331
	C1(MP,NQ,3)=C1(MP,NQ,1)	PEST	332
644	CONTINUE	PEST	333
	GO TO 700	PEST	334
C		C PEST	335
C **	PORHOLT.	** C PEST	336
645	PORA(MP,1,3)=PORA(MP,1,1) \$ PORB(MP,1,3)=PORB(MP,1,1)	PEST	337
	RHOP(MP,5,3) = RHOP(MP,5,1) \$ RHOP(MP,2,3) = RHOP(MP,2,1)	PEST	338
	RHOP(MP,3,3) = RHOP(MP,3,1) \$ YADDP(MP,1,3) = YADDP(MP,1,1)	PEST	339
	RHOP(MP,1,3)=RHOP(MP,1,1)	PEST	340
	GO TO 700	PEST	341
C		C PEST	342
C **	CARROLL-HOLT MODEL.	** C PEST	343
647	APC(MP,3)=APC(MP,1) \$ EPS(MP,3)=EPS(MP,1)	PEST	344
	DEL(MP,3)=DEL(MP,1) \$ RHOP(MP,5,3)=RHOP(MP,5,1)	PEST	345
	RHOP(MP,1,3)=RHOP(MP,1,1)	PEST	346
	GO TO 700	PEST	347
C **	HERRMANN P-ALPHA MODEL.	** C PEST	348
648	PORA(MP,1,3) = PORA(MP,1,1) \$ PORC(MP,1,3) = PORC(MP,1,1)	PEST	349
	RHOP(MP,1,3) = RHOP(MP,1,1)	PEST	350
	GO TO 700	PEST	351
660	GO TO (490,510,520,530,540,550) KRSM	PEST	352
C		C PEST	353
C ***	READ FOR RATE EFFECTS IN COMPRESSION.	*** C PEST	354
C		C PEST	355
700	N = 1	PEST	356
	J2=5HCOMP, \$ J3=J4=1H	PEST	357
	IF (KTDN .EQ. 0) J3=5HTENS, \$ IF (KRDM .EQ. 0) J4=5HRECOM	PEST	358
	IF (KCDM .LE. 0) GO TO 750	PEST	359
	GO TO (750,720,730,740) KCDM	PEST	360
720	CONTINUE	PEST	361
C		C PEST	362
C **	READ AND INIT FOR LINEAR VISCOUS VOID(C) OR DUCTILE FRACTURE(T)	PEST	363
	READ(IN,909)A1,(TER(MP,1,N),I=1,7)	PEST	364
	WRITE(6,910)A1,(TER(MP,1,N),I=1,7)	PEST	365
	IF (N .EQ. 1 .OR. N .EQ. 3) WRITE(6,960)IDD,IN,JQ11,JQ12,JQR,	PEST	366
1	J2,J3,J4	PEST	367
	IF (N .EQ. 2) WRITE(6,960)IDD,IN,JQ17,JQ18,JQR,J2	PEST	368
	IF (TER(MP,8,N) .EQ. 0.)TER(MP,8,N)=8.*3.14159*TER	PEST	369
1	(MP,3,N)**3*TER(MP,4,N)	PEST	370
	GO TO 750	PEST	371
730	CONTINUE	PEST	372
C		C PEST	373
C **	READ AND INIT DYNAMIC PORHOLT.	** C PEST	374
	READ(IN,919)A1,TPH(MP,N)	PEST	375
	WRITE(6,920)A1,TPH(MP,N)	PEST	376

SUBROUTINE PEST (Continued)

WRITE(6,960)IDD,IN,JQ13,JQ14,JQR,J2,J3,J4	PEST	377
GO TO 750	PEST	378
740 CONTINUE	PEST	379
C	C PEST	380
C * READ AND INIT DYNAMIC BUTCHER P-ALPHA-TAU.	** C PEST	381
READ(IN,919)A1,TPH(MP,N)	PEST	382
WRITE(6,920)A1,TPH(MP,N)	PEST	383
DADP(MP,N)=-ALF0/AK(MP)*(1.-AK(MP)*ALF0/EQSTCM)	PEST	384
WRITE(6,960)IDD,IN,JQ13,JQ16,JQR,J2,J3,J4	PEST	385
750 N = N+1	PEST	386
C	C PEST	387
C *** READ FOR RATE EFFECTS IN TENSION.	*** C PEST	388
C	C PEST	389
GO TO(700,755,770,900) N	PEST	390
755 J2=5HTENS	PEST	391
IF (KTDN .GT. 0) GO TO (750,720,760) KTDN	PEST	392
IF (KCDN .EQ. 0) GO TO 750	PEST	393
C	C PEST	394
C ** REPEAT ARRAYS KTD=KCD.	** C PEST	395
IF (KCDN .EQ. 1) GO TO 750	PEST	396
IF (KCDN .GT. 2) GO TO 756	PEST	397
C	C PEST	398
C ** REPEAT LINEAR VISCOUS VOID FOR DUCTILE FRACTURE.	** C PEST	399
TER(MP,1,2)=TER(MP,1,1) \$ TER(MP,2,2)=-TER(MP,2,1)	PEST	400
TER(MP,3,2)=TER(MP,3,1) \$ TER(MP,4,2)=TER(MP,4,1)	PEST	401
TER(MP,5,2)=-TER(MP,5,1) \$ TER(MP,6,2)=TER(MP,6,1)	PEST	402
TER(MP,7,2) = TER(MP,7,1) \$ TER(MP,8,2) = TER(MP,8,1)	PEST	403
GO TO 750	PEST	404
C	C PEST	405
C ** READ BRITTLE FRACTURE AND FRAGMENTATION.	** C PEST	406
756 CONTINUE	PEST	407
760 CONTINUE	PEST	408
GO TO 750	PEST	409
C	C PEST	410
C *** READ FOR RATE EFFECTS IN RECOMPRESSION.	*** C PEST	411
770 J2=5HRECOM	PEST	412
IF (KRDM .GT. 0) GO TO 800	PEST	413
C	C PEST	414
C ** REPEAT ARRAYS KRD=KCD AS FOLLOWS.	** C PEST	415
IF (KCDN .EQ. 0) GO TO 900	PEST	416
GO TO (900,780,785,790) KCDN	PEST	417
C	C PEST	418
C ** REPEAT FOR LINEAR VISCOUS VOID COMPRESSION MODEL.	** C PEST	419
780 TER(MP,1,3)=TER(MP,1,1) \$ TER(MP,2,3)=TER(MP,2,1)	PEST	420
TER(MP,3,3) = TER(MP,3,1) \$ TER(MP,4,3) = TER(MP,4,1)	PEST	421
TER(MP,5,3) = TER(MP,5,1) \$ TER(MP,6,3) = TER(MP,6,1)	PEST	422
TER(MP,7,3) = TER(MP,7,1) \$ TER(MP,8,3) = TER(MP,8,1)	PEST	423
GO TO 900	PEST	424
C	C PEST	425
C ** REPEAT FOR DYNAMIC PORHOLT MODEL.	** C PEST	426
785 TPH(MP,3)=TPH(MP,1)	PEST	427
GO TO 900	PEST	428
C	C PEST	429
C ** REPEAT FOR BUTCHER P-ALPHA-TAU MODEL.	** C PEST	430
790 TPH(MP,3)=TPH(MP,1) \$ DADP(MP,3)=DADP(MP,1)	PEST	431
GO TO 900	PEST	432
800 GO TO (900,720,730,740) KRDM	PEST	433
900 RETURN	PEST	434
905 FORMAT(8A10)	PEST	435
909 FORMAT(A10,7E10.3)	PEST	436
910 FORMAT(A10,1P7E10.3)	PEST	437
915 FORMAT(1X,2A1)	PEST	438
919 FORMAT(4(A10,E10.3))	PEST	439
920 FORMAT(4(A10,1PE10.3))	PEST	440
925 FORMAT(* PY=*1PE10.3,* PC=*1PE10.3,* EPS=*1PE10.3)	PEST	441
927 FORMAT(* ABSOLUTE VALUE OF CONSOLIDATION PRESSURE WAS CHANGED TO	PEST	442
1 BE WITHIN ALLOWABLE RANGE*)	PEST	443
930 FORMAT(/)	PEST	444
932 FORMAT(* CONSOLIDATION DENSITY=*1PE10.3)	PEST	445
935 FORMAT(2(A10,I6,I2,I2))	PEST	446
939 FORMAT(A10,I10,A10,E10.3)	PEST	447
940 FORMAT(A10,I10,A10,1PE10.3)	PEST	448
950 FORMAT(* BULK AND SHEAR MODULI ARE CHANGED TO*1P2E12.3,* DYN/CM2*)	PEST	449
960 FORMAT(1H+,79X,5H IND=A2,5H, IN=I2,A10,A9,4A5)	PEST	450
C	C PEST	451

SUBROUTINE PEST (Continued)

C	*****	*****	C PEST 452
C	COMPUTATION OF PRESSURE DURING WAVE PROPAGATION.	C	PEST 453
C	*****	*****	C PEST 454
C		C	PEST 455
1000	MP = NPM(M) IH=H	PEST	456
C		PEST	457
C **	COMPUTE BULK AND SHEAR MODULI APPROPRIATE TO CURRENT E AND D.	C	PEST 458
C		C	PEST 459
	TF = 1.+E*EQSTGM*RHOS/EQSTCM	PEST	460
	DREF = D*TF	PEST	461
	RVV1=ABS(RVV) \$ ALFD1=1./((1.-RVV1)	PEST	462
	IF (RVV .LT. 0. .AND. DREF/RHOS .LT. 1.-ABS(RVV)) GO TO 2000	PEST	463
	IF (NCYC .LE. 1) ALFS = RHOS/RHOP(MP,6,1)	PEST	464
	IF (F .EQ. 0.) GO TO 1800	9/12/79	13
	IF (H .EQ. 5R S .OR. H .EQ. 5R M) GO TO 1800	PEST	466
	RHOPV=RHOS/TF+(RHOP(MP,5,1)-RHOS)*F	PEST	467
	RHOM=RHOP(MP,6,1)/TF	PEST	468
	ALF=AMAX1(1.0,RHOPV/D) \$ ALFZ=RHOPV/RHOM	PEST	469
	ELK=(EQSTCM/AK(MP)-ALFZ)/(ALFZ-1.)	PEST	470
	ELG=(1.-MUP(MP)*F/MUM)/(1.-1./ALFZ)	PEST	471
	BULK=EQSTCM*F/(ALF+ELK*(ALF-1.))	PEST	472
	MUM=AMAX1(0.,MUM*(1.-ELG+ELG/ALF))	PEST	473
	C=SQRT((BULK+MUM)/D)	PEST	474
	IF (NCYC .EQ. 0) PRINT 2300,D,BULK,MUM,C,F,ELK,ELG,RHOP(MP,6,1),	9/12/79	14
1	E	9/12/79	15
C		C	PEST 477
C ***	COMPUTE PRESSURE FROM ELASTIC RELATIONS.	*** C	PEST 478
	PEL=P+BULK*((D-DOLD)/(0.5*(D+DOLD))+EQSTGM*RHOS/EQSTCM*(E-EOLD))	C	PEST 479
C		C	PEST 480
C **	BRANCH TO TENSILE OR COMPRESSIVE ROUTES.	** C	PEST 481
C		C	PEST 482
	IF (PEL .LT. 0.) GO TO 1500	PEST	483
C		C	PEST 484
C ***	COMPRESSION PATH.	*** C	PEST 485
C		C	PEST 486
	KCRS=KCS(MP) \$ N=1	PEST	487
	IF (H .EQ. 5R T) H = 5R Q	PEST	488
	IF (H .NE. 5R Z .AND. H .NE. 5R R) GO TO 1090	PEST	489
	H = 5R R	PEST	490
	KCRS = KRS(MP)	PEST	491
	IF (KRS(MP) .EQ. 0) KCRS = KCS(MP)	PEST	492
	N = 3	PEST	493
1090	GO TO (1100,1120,1140,1160,1180) KCRS	PEST	494
C		C	PEST 495
C ***	CALCULATION OF COMPACTION CURVE.	*** C	PEST 496
C		C	PEST 497
C **	PQREQST MODEL.	** C	PEST 498
1100	NC = 0	PEST	499
	PST = 0.	PEST	500
	IF (DREF .GT. RHOP(MP,5,N))GO TO 1109	PEST	501
1105	NC = NC+1	PEST	502
	IF (DREF .GT. RHOP(MP,NC,N)) GO TO 1105	PEST	503
	PST = F*(PORA(MP,NC,N)+PORB(MP,NC,N)/DREF+PORC(MP,NC,N)/DREF**2)	PEST	504
	NQ = MAX0(1,NC-1)	PEST	505
	CZJ = COSQ(MP,NQ,N) \$ CWJ = C1(MP,NQ,N)	PEST	506
	YADDM = YADDP(MP,NQ,N)	PEST	507
C		C	PEST 508
C *	CHECK FOR CONSOLIDATION IN LAST POROUS REGION.	* C	PEST 509
1108	IF (DREF .LT. RHOS) GO TO 1300	PEST	510
1109	GO TO (1110,1112,1114) NPRM	PEST	511
1110	CALL EQST(E,D,PS,M,CJ,DPDDJ,DPDEJ)	PEST	512
	GO TO 1118	PEST	513
1112	CALL ESA(1,5,M,CJ,D,E,PS,DPDDJ,DPDEJ)	PEST	514
	GO TO 1118	PEST	515
1114	CALL EQSTPF(1,5,M,CJ,D,E,PS)	PEST	516
1118	IF (PS .LT. PST) GO TO 1300	PEST	517
	PST = PS	PEST	518
	IH = 5R S	PEST	519
	IF (PS .LT. PEL) GO TO 1300	PEST	520
	PJ = PS \$ H = 5R S \$ RVV = 0.	PEST	521
	GO TO 1900	PEST	522
C		C	PEST 523
C **	PORHOLT MODEL.	** C	PEST 524
1120	DREF=AMAX1(DREF,RHOP(MP,1,N))	PEST	525

SUBROUTINE PEST (Continued)

	ALFS = (RHOP(MP,3,N)+(PORC(MP,1,N)+PORB(MP,1,N)*(DREF-RHOP(MP,2,N)	PEST	526
	1))* (DREF-RHOP(MP,2,N)))/DREF	PEST	527
	ALFS=AMAX1(ALFS,1.)	PEST	528
	DS = ALFS*DREF	PEST	529
	GO TO (1126,1128,1130) NPRM	PEST	530
1126	CALL EQST(0.,DS,PS,M,CJ,DPDDJ,DPDEJ)	PEST	531
	GO TO 1134	PEST	532
1128	CALL ESA(1,5,M,CJ,DS,0.,PS,DPDDJ,DPDEJ)	PEST	533
	GO TO 1134	PEST	534
1130	CALL EQSTPF(1,5,M,CJ,DS,0.,PS)	PEST	535
1134	PST = PS/ALFS*F	PEST	536
	YADDM = YADDP(MP,1,N)	PEST	537
	GO TO 1108	PEST	538
C		C PEST	539
C **	CARROLL-HOLT MODEL.	** C PEST	540
1140	BNEW = 1.0	PEST	541
	IF (DREF .GT. RHOP(MP,5,N)) GO TO 1143	PEST	542
	BNEW = BP = DREF/RHOS	PEST	543
	IF (BNEW .GT. 2.-1./APC(MP,N)) BNEW = 1.+0.5*(BP-1./APC(MP,N))	PEST	544
	NW = 0	PEST	545
1141	B1 = BP+DEL(MP,N)*ALOG(EPS(MP,N)-BNEW)	PEST	546
	BNEW = AMIN1(BNEW+(B1-BNEW)/(1.+DEL(MP,N)/(EPS(MP,N)-BNEW)),0.9999	PEST	547
	19999)	PEST	548
	NW = NW+1	PEST	549
	AW = NW	PEST	550
	IF (ABS(BNEW-B1) .GT. 1.E-6 .AND. AW .LT. 10.) GO TO 1141	PEST	551
1143	DS = DREF/BNEW	PEST	552
	GO TO (1145,1147,1149) NPRM	PEST	553
1145	CALL EQST(0.,DS,PS,M,CJ,DPDDJ,DPDEJ)	PEST	554
	GO TO 1155	PEST	555
1147	CALL ESA(1,5,M,CJ,DS,0.,PS,DPDDJ,DPDEJ)	PEST	556
	GO TO 1155	PEST	557
1149	CALL EQSTPF(1,5,M,CJ,DS,0.,PS)	PEST	558
1155	PST = PS*BNEW*F	PEST	559
	GO TO 1108	PEST	560
1160	CONTINUE	PEST	561
C		C PEST	562
C **	HERRMANN P-ALPHA.	** C PEST	563
	PST = 0.	PEST	564
	DC = RHOS*(PORC(MP,1,N)*F/EQSTCM+1.)/TF	PEST	565
	DC = RHOS*(1.+TSQE(0,PORC(MP,1,N)*F,EQSTGM*DC*E,EQSTCM,	PEST	566
1	EQSTDM,EQSTSM,EQSTGM,EQSTHM,EQSTEM,RHOS,EQSTNM,E,EQSTVM,EQSTAM,	PEST	567
2	NCYC))	PEST	568
	IF (DC .LT. D) GO TO 1109	PEST	569
	DY = RHOP(MP,1,N)/TF*(1.+PORC(MP,1,N)/AK(MP))	PEST	570
	ALFY = 1./(DY*TF/RHOS-PORC(MP,1,N)*F/EQSTCM)	PEST	571
	DD = AMAX1(D,DY)	PEST	572
	DYD = DY*ALFY/DD	PEST	573
	DCD = DC/DD	PEST	574
	B1 = (DCD-DYD)**2/(ALFY - 1.)	PEST	575
	B2 = DCD+B1/2.	PEST	576
	ALFS = B2-SQRT(B2*B2-DCD*DCD-B1)	PEST	577
	DS = ALFS*DD	PEST	578
	GO TO (1170,1172,1174) NPRM	PEST	579
1170	CALL EQST(E,DS,PS,M,CJ,DPDDJ,DPDEJ)	PEST	580
	GO TO 1178	PEST	581
1172	CALL ESA(1,5,M,CJ,DS,E,PS,DPDDJ,DPDEJ)	PEST	582
	GO TO 1178	PEST	583
1174	CALL EQSTPF(1,5,M,CJ,DS,E,PS)	PEST	584
1178	IF(D .GE. DY) GO TO 1179	PEST	585
	DYD = DY*ALFY/D	PEST	586
	DCD = DC/D	PEST	587
	B1 = (DCD-DYD)**2/(ALFY - 1.)	PEST	588
	B2 = DCD+B1/2.	PEST	589
	ALFS = B2-SQRT(B2*B2-DCD*DCD-B1)	PEST	590
1179	PST = PS/ALFS	PEST	591
	IF (PEL .LT. PST) GO TO 1300	PEST	592
	PJ = PST	PEST	593
1180	CONTINUE	PEST	594
1300	PJ = PEL	PEST	595
	IF (PST .LT. PEL) PJ = PST	PEST	596
C		C PEST	597
C *	COMPUTE RELATIVE VOID VOLUME.(RVV)	* C PEST	598
C		C PEST	599
	PTH=TSQE(1,PJ*RHOS/D,EQSTGM*RHOS*E,EQSTCM,EQSTDM,EQSTSM,EQSTGM,	PEST	600

SUBROUTINE PEST (Continued)

1	EQSTHM, EQSTEM, RHOS, EQSTNM, E, EQSTVM, EQSTAM, NCYC)	PEST	601
	IF (PJ .NE. 0.) RVV=AMAX1(1.-PJ/PTH, 0.)	PEST	602
	IF (PJ .EQ. 0.) RVV=AMAX1(0., 1.-D/PTH)	PEST	603
	ALFS=1./(1.-RVV)	PEST	604
	IF (AST1 .EQ. 0.) AST1 = ALFS	PEST	605
	IF (PEL .GT. PST) GO TO 1310	PEST	606
	IF (IH .NE. 5R S) GO TO 1900	PEST	607
	RVV = 0. \$ H = 5R S \$ GO TO 1900	PEST	608
C		C PEST	609
C ***	DYNAMIC PRESSURE.	*** C PEST	610
C		C PEST	611
1310	KCRD=KCD(MP)	PEST	612
	IF (H .EQ. 5R R .AND. KRD(MP) .NE. 0) KCRD = KRD(MP)	PEST	613
	IF (KCRD .GT. 1) GO TO 1320	PEST	614
C		C PEST	615
C **	NO RATE-DEPENDENCE.	** C PEST	616
	IF (IH .EQ. 5R S) H = 5R S	PEST	617
	GO TO 1900	PEST	618
1320	PELS=TSQE(1, PEL*RHOS/D, EQSTGM*RHOS*E, EQSTCM, EQSTDM, EQSTSM, EQSTGM,	PEST	619
1	EQSTHM, EQSTEM, RHOS, EQSTNM, E, EQSTVM, EQSTAM, NCYC)	PEST	620
	IF (PEL .NE. 0.) ALFL=PELS/PEL	PEST	621
	IF (PEL .EQ. 0.) ALFL=PELS/D	PEST	622
	ALFSD = (ALFS-AST1)/DT	PEST	623
	ALFLD = (ALFL - ALFD1)/DT	PEST	624
	GO TO (1900, 1340, 1380, 1440) KCRD	PEST	625
C		C PEST	626
C **	LINEAR VISCOUS VOID COMPACTION.	** C PEST	627
1340	VVE = 1.-1./ALFL	PEST	628
	DV = DV0 = 1./D-1./D0LD	PEST	629
	NLOOP=MAX1(1., -DV*EQSTCM*D/AMAX1(PST, P)/ALF+0.8, -4.*TER(MP, 1, N)*DT	PEST	630
1	*(P-PST1))	PEST	631
	V0LD = 1./D0LD \$ VS0 = (1.-RVV1)/D0LD	PEST	632
	NTRY = 0	PEST	633
	RVVL = RVV1	PEST	634
	PTHL = PTH0 = PST1*AST1	PEST	635
	PS0 = AMAX1(P, PST1)/(1.-RVV1)	PEST	636
	IF (PST1 .LT. 0.) PS0=PTHL=PTH0=0.	PEST	637
	IF (1.-RVV1 - 1./AST1 .LT. 0. .AND. PS0 .GT. PTH0) GO TO 13401	PEST	638
	RVPO = -1./(D0LD*EQSTCM)	PEST	639
	DRVPO = 0.	PEST	640
	GO TO 13403	PEST	641
13401	RVPO = (1.-RVV1-1./AST1)/D0LD/(PS0-PTH0)	PEST	642
	DRVPO = (RVV-VVE)/D/(PELS-PTH)-RVPO	PEST	643
13403	VSTH0 = 1./(D0LD*AST1)	PEST	644
	IF (PST1 .LE. 0. .OR. PST1 .GT. P) PTHL=PTH0=PTH	PEST	645
	DVSTH = (1.-RVV)/D-VSTH0	PEST	646
	DVDP = (VVE/D-RVV1/D0LD)/(PELS-PS0)	PEST	647
	DPH = PTH-PTH0	PEST	648
1341	DELV = DV/NLOOP \$ VH = V0LD \$ DTN = DELV/DV0*DT	PEST	649
	A1 = TER(MP, 1, N)*DTN	PEST	650
C	BEGIN DO LOOP FOR SUBCYCLING	PEST	651
	DO 1347 NL = 1, NLOOP	PEST	652
	VH = VH+DELV \$ RATIO = (VH-1./D0LD)/DV0	PEST	653
	RVP = RVPO+DRVPO*RATIO	PEST	654
	VSTH = VSTH0+DVSTH*RATIO	PEST	655
	PTHH = PTH0+DPH*RATIO	PEST	656
C	FIRST ESTIMATE OF PRESSURE IN SOLID	PEST	657
	DP = AMAX1(0., PS0-PTHL)	PEST	658
	XG = 1. \$ IF (DP .GE. 0.) XG = EXP(A1*DP)	PEST	659
	PL0 = PTHH \$ PUP = PELH = AMAX1(P, PST1)/(1.-RVV1)+(PELS-AMAX1(P,	PEST	660
1	PST1)/(1.-RVV1))*RATIO	PEST	661
	PSA = PELH \$ ZG = RVVL*VH	PEST	662
	IF (PTHH .GT. PELH) GO TO 1346	PEST	663
	PSJ = (DELV+VS0-VSTH+PTHH*RVP+PS0*DVDP-RVVL*VH*(XG*(1.+A1/2.*	PEST	664
1	(-PTHH-PS0+PTHL))-1.))/(RVP+DVDP+RVVL*VH*XG*A1/2.)	PEST	665
	NC = 0	PEST	666
1342	NC = NC+1	PEST	667
	DP = (AMAX1(0., PSJ-PTHH)+AMAX1(0., PS0-PTHL))/2.	PEST	668
	ZG = RVVL*VH \$ IF (DP .GE. 0.) ZG = ZG*EXP(A1*DP)	PEST	669
	DELVA = VSTH-VS0+RVP*(PSJ-PTHH)+DVDP*(PSJ-PS0)+ZG-RVVL*VH	PEST	670
	PSA = PSJ	PEST	671
	AC = NC	PEST	672
	IF (ABS(DELVA-DELV) .LT. 1.E-5*VH .OR. (PSJ .LE. PTHH .AND. AC	PEST	673
1	.GT. 1.)) GO TO 1346	PEST	674
	IF (NC .GE. 10) GO TO 1348	PEST	675

SUBROUTINE PEST (Continued)

	IF (DELVA .GT. DELV) PLO = AMAX1(PSA,PLO)	PEST	676
	IF (DELVA .LT. DELV) PUP = AMIN1(PSA,PUP)	PEST	677
C	MAKE 2ND ESTIMATE OF PRESSURE IN THE SOLID	PEST	678
	IF (MOD(NC,2) .EQ. 0) GO TO 1343	PEST	679
	PSJ = PSJ+(DELV-DELVA)/(RVP+DVDP+ZG*A1/2.)	PEST	680
	GO TO 1344	PEST	681
C	INTERPOLATION ESTIMATE OF PRESSURE IN SOLID	PEST	682
1343	PSJ = PSA+(DELV-DELVA)/(DELVB-DELVA)*(PSB-PSA)	PEST	683
1344	CONTINUE	PEST	684
	IF (PSJ .GT. PUP) PSJ = PUP-1.E7	PEST	685
	IF (PSJ .LT. PLO) PSJ = PLO+1.E7	PEST	686
	IF (NC .EQ. 1) GO TO 1345	PEST	687
	IF (ABS(DELVA-DELV) .GT. ABS(DELVB-DELV)) GO TO 1342	PEST	688
1345	PSB = PSA \$ DELVB = DELVA \$ GO TO 1342	PEST	689
C	CONCLUSION OF LOOP	PEST	690
1346	RVVL = ZG/VH \$ PTHL = PTHH \$ PSA = PSO = AMAX1(PTHH,AMIN1	PEST	691
	1 (PELH,PSA))	PEST	692
	VSQ = VH-ZG \$ ENT = ENT*VOLD/VH	PEST	693
1347	CONTINUE	PEST	694
	PJ = (1.-RVVL)*PSA \$ RVV = RVVL \$ GO TO 1900	PEST	695
C	PROVISION FOR ABORT FOR ITERATION FAILURE	PEST	696
1348	NTRY = NTRY+1 \$ IF (NTRY .GE. 5) GO TO 1349	PEST	697
	VOLD = VH-DELV \$ DV = 1./D-VOLD	PEST	698
	NLOOP = MAX1(3.,-2.**NTRY*DV*EQSTCM*D/AMAX1(PST,P)/ALF+0.8)	PEST	699
	GO TO 1341	PEST	700
1349	WRITE(6,2349)M,P,DV,DELVA,DELVB	PEST	701
	GO TO 1346	PEST	702
C		PEST	703
C **	PORHOLT MODEL - DYNAMIC.	** C PEST	704
1380	ALFD = TPH(MP,N)*ALFLD +AST1 +ALFSD*(DT-TPH(MP,N))+(ALFD1-TPH(	PEST	705
	1 MP,N)*ALFLD-AST1+TPH(MP,N)*ALFSD)*EXP(-DT/TPH(MP,N))	PEST	706
1382	DS = ALFD*D	PEST	707
	GO TO (1385,1390,1395) NPRM	PEST	708
1385	CALL EQST(E,DS,PS,M,CJ,DPDDJ,DPDEJ)	PEST	709
	GO TO 1400	PEST	710
1390	CALL ESA(1,5,M,CJ,DS,E,PS,DPDDJ,DPDEJ)	PEST	711
	GO TO 1400	PEST	712
1395	CALL EQSTPF(1,5,M,CJ,DS,E,PS)	PEST	713
1400	PJ=AMIN1(PEL,AMAX1(PST,PS/ALFD))	PEST	714
	PS1=TSQE(1,PJ*RHOS/D,EQSTGM*RHOS*E,EQSTCM,EQSTDM,EQSTSM,EQSTGM,	PEST	715
	1 EQSTHM,EQSTEM,RHOS,EQSTNM,E,EQSTVM,EQSTAM,NCYC)	PEST	716
	IF (PJ .NE. 0.) RVV=AMAX1(0.,1.-PJ/PS1)	PEST	717
	IF (PJ .EQ. 0.) RVV=AMAX1(0.,1.-D/PS1)	PEST	718
	GO TO 1900	PEST	719
C **	BUTCHER P-ALPHA-TAU	** C PEST	720
1440	CONTINUE	PEST	721
	BT=TPH(MP,N)*(ALFL-ALFS)/DADP(MP,N)/(PEL-PST)	PEST	722
	ALFD=((ALFL-ALFD1)*BT/DT-ALFS+ALFD1)*EXP(DT/BT)+ALFS-(ALFL-ALFD1)*	PEST	723
	1 BT/DT	PEST	724
	IF (ALFD .LT. ALFS) ALFD = ALFS	PEST	725
	IF (ALFD .GT. ALFL) ALFD = ALFL	PEST	726
	GO TO 1382	PEST	727
C		C PEST	728
C ***	TENSILE PATH.	*** C PEST	729
C **	STATIC FRACTURE THRESHOLD CURVE.	** C PEST	730
C		C PEST	731
1500	KTSS = KTS(MP)	PEST	732
	IF(KTSS .EQ. 0) KTSS = KCS(MP)	PEST	733
	N = 2	PEST	734
	GO TO (1520,1540,1560) KTSS	PEST	735
C		C PEST	736
C **	VARIABLE STRENGTH.	PEST	737
1520	PTH = TER(MP,5,N)*F	PEST	738
	PST = D*PTH*(1./RHOS+EQSTGM*E/EQSTCM)/(1.+PTH/EQSTCM)	PEST	739
	GO TO 1600	PEST	740
C		C PEST	741
C **	FRACTURE MECHANICS.	** C PEST	742
1540	GO TO 1520	PEST	743
C		C PEST	744
C **	CARROLL-HOLT THRESHOLD STRESS.	** C PEST	745
1560	PST = PEL	PEST	746
	IF (DREF .GT. RHOP(MP,5,N)) GO TO 1600	PEST	747
	BNEW = BP = DREF/RHOS	PEST	748
	NW = 0	PEST	749
1565	B1 = BP+DEL(MP,N)*ALOG(EPS(MP,N)-BNEW)	PEST	750

SUBROUTINE PEST (Continued)

BNEW = AMIN1(BNEW+(B1-BNEW)/(1.+DEL(MP,N)/(EPS(MP,N)-BNEW)),0.9999	PEST	751
19999)	PEST	752
NW = NW+1	PEST	753
AW = NW	PEST	754
IF (ABS(BNEW-B1) .GT. 1.E-6 .AND. AW .LT. 10.) GO TO 1565	PEST	755
DS = DREF/BNEW	PEST	756
GO TO (1570,1572,1574) NPRM	PEST	757
1570 CALL EQST(0.,DS,PS,M,CJ,DPDDJ,DPDEJ)	PEST	758
GO TO 1580	PEST	759
1572 CALL ESA(1,5,M,CJ,DS,0.,PS,DPDDJ,DPDEJ)	PEST	760
GO TO 1580	PEST	761
1574 CALL EQSTPF(1,5,M,CJ,DS,0.,PS)	PEST	762
1580 PST = PS*BNEW*F	PEST	763
IF (PST .GT. PS) GO TO 1600	PEST	764
PST = PS	PEST	765
IH = 5R S	PEST	766
IF (PEL .GT. PS) GO TO 1600	PEST	767
PJ = PS	PEST	768
H = 5R S \$ RVV = 0.	PEST	769
GO TO 1900	PEST	770
1600 PJ = PEL	PEST	771
IF (H .NE. 5R S) H = 5R T	PEST	772
IF (PEL .LT. PST) H = 5R T	PEST	773
IF (PEL .LT. PST) PJ = PST	PEST	774
C	C PEST	775
C ** COMPUTE RELATIVE VOID VOLUME. (RVV)	** C PEST	776
C	C PEST	777
PTH=TSQE(1,PJ*RHOS/D,EQSTGM*RHOS*E,EQSTCM,EQSTDM,EQSTSM,EQSTGM,	PEST	778
1 EQSTHM,EQSTEM,RHOS,EQSTNM,E,EQSTVM,EQSTAM,NCYC)	PEST	779
IF (PJ .NE. 0.) RVV = AMAX1(0.,1.-PJ/PTH)	PEST	780
IF (PJ .EQ. 0.) RVV=AMAX1(0.,1.-D/PTH)	PEST	781
ALFS = 1./(1.-RVV)	PEST	782
IF (RVV .GT. TER(MP,7,N)) GO TO 2000	PEST	783
IF (PEL .GE. PST) GO TO 1900	PEST	784
C	C PEST	785
C ** DYNAMIC TENSILE PRESSURE.	** C PEST	786
C	C PEST	787
KTDD = KTD(MP)	PEST	788
IF (KTDD .EQ. 0) KTDD = KCD(MP)	PEST	789
IF (KTDD .EQ. 0 .AND. KCDM .EQ. 0) KTDD = 1	PEST	790
GO TO (1615,1620,1660) KTDD	PEST	791
C	C PEST	792
C ** NO RATE DEPENDENCE.	** C PEST	793
1615 PJ = PST	PEST	794
GO TO 1635	PEST	795
C	C PEST	796
C ** N. A. G. DUCTILE FRACTURE MODEL.	** C PEST	797
1620 DV = DV0 = 1./D-1./DOLD	PEST	798
VVE = 1.-PEL/TSQE(1,PEL*RHOS/D,EQSTGM*RHOS*E,EQSTCM,EQSTDM,EQSTSM,	PEST	799
1 EQSTGM,EQSTHM,EQSTEM,RHOS,EQSTNM,E,EQSTVM,EQSTAM,NCYC)	PEST	800
IF (AST1 .EQ. 0.) AST1 = ALFS	PEST	801
PELS = PEL/(1.-VVE)	PEST	802
NLOOP=MAX1(1.,-DV*EQSTCM*D/AMIN1(PST,P)/ALF+0.8,4.*TER(MP,1,N)*DT	PEST	803
1 *(P-PST1))	PEST	804
VOLD = 1./DOLD \$ VS0 = (1.-RVV1)/DOLD	PEST	805
NTRY = 0	PEST	806
RVVL = RVV1	PEST	807
PTHL = PTH0 = PST1*AST1	PEST	808
PS0 = AMIN1(P,PST1)/(1.-RVV1)	PEST	809
IF (PST1 .GT. 0.) PS0=PTHL=PTH0=0.	PEST	810
IF (1.-RVV1 - 1./AST1 .GT. 0..AND. PS0 .LT. PTH0) GO TO 16201	PEST	811
DRVP = 0.	PEST	812
RVPO = -1./(DOLD*EQSTCM)	PEST	813
GO TO 16203	PEST	814
16201 RVPO = (1.-RVV1-1./AST1)/DOLD/(PS0-PTH0)	PEST	815
DRVP = (RVV-VVE)/D/(PELS-PTH)-RVPO	PEST	816
16203 VSTH0 = 1./(DOLD*AST1)	PEST	817
DVSTH = (1.-RVV)/D-VSTH0	PEST	818
DVDP = (VVE/D-RVV1/DOLD)/(PELS-PS0)	PEST	819
IF (PST1 .EQ. 0. .OR. PST1 .LT. P) PTHL = PTH0 = PTH	PEST	820
DPTH = PTH-PTH0	PEST	821
1621 DELV = DV/NLOOP \$ VH = VOLD \$ DTN = DELV/DV0*DT	PEST	822
A1 = TER(MP,1,N)*DTN	PEST	823
C BEGIN DO LOOP FOR SUBCYCLING	PEST	824
DO 1632 NL = 1,NLOOP	PEST	825

SUBROUTINE PEST (Continued)

VH = VH+DELV \$ RATIO = (VH-1./DOLD)/DV0	PEST	826
RVP = RVP0+DRV*P*Ratio	PEST	827
VSTH = VSTH0+DVSTH*Ratio	PEST	828
PTHH = PTH0+DP*TH*Ratio	PEST	829
C FIRST ESTIMATE OF PRESSURE IN SOLID	PEST	830
DP = AMIN1(0.,PS0-PTHL)	PEST	831
XG = 1. \$ XN = 0.	PEST	832
IF (DP .GE. 0.) GO TO 1622	PEST	833
XG = EXP(A1*DP)	PEST	834
XN = EXP(DP/TER(MP,6,N))	PEST	835
1622 PL0 = PTHH \$ PUP = PELH = AMIN1(P, PST1)/(1.-RVV1)+(PELS-AMIN1(P,	PEST	836
1 PST1)/(1.-RVV1))*Ratio	PEST	837
ZG = RVVL*VH \$ ZN = 0. \$ PSA = PELH	PEST	838
IF (PTHH .LT. PELH) GO TO 1630	PEST	839
PSJ = (DELV+VS0-VSTH+PTHH*RVP+PS0*DVP-RVVL*VH*(XG*(1.+A1/2.*	PEST	840
1 (-PTHH-PS0+PTHL))-1.)-TER(MP,8,N)*VH*DTN*XN*(1.-(PTHH+PS0-PTHL)/	PEST	841
2 2./TER(MP,6,N)))/(RVP+DVP+RVVL*VH*XG*A1/2.+TER(MP,8,N)*VH*DTN*	PEST	842
3 XN/2./TER(MP,6,N))	PEST	843
NC = 0	PEST	844
1623 NC = NC+1	PEST	845
DP = (AMIN1(0.,PSJ-PTHH)+AMIN1(0.,PS0-PTHL))/2.	PEST	846
ZG = RVVL*VH \$ ZN = 0.	PEST	847
IF (DP .GE. 0.) GO TO 1624	PEST	848
ZG = ZG*EXP(A1*DP)	PEST	849
ZN = TER(MP,8,N)*VH*DTN*EXP(DP/2./TER(MP,6,N))	PEST	850
1624 DELVA = VSTH-VS0+RVP*(PSJ-PTHH)+DVP*(PSJ-PS0)+ZG-RVVL*VH+ZN	PEST	851
PSA = PSJ	PEST	852
AC = NC	PEST	853
IF (ABS(DELVA-DELV) .LT. 1.E-5*VH .OR. (PSJ .GE. PTHH .AND. AC	PEST	854
1 .GT. 1.)) GO TO 1630	PEST	855
IF (NC .GE. 10) GO TO 1640	PEST	856
IF (DELVA .LT. DELV) PL0 = AMIN1(PL0,PSA)	PEST	857
IF (DELVA .GT. DELV) PUP = AMAX1(PSA,PUP)	PEST	858
C MAKE 2ND ESTIMATE OF PRESSURE IN THE SOLID	PEST	859
IF (MOD(NC,2) .EQ. 0) GO TO 1625	PEST	860
PSJ = PSJ+(DELV-DELVA)/(RVP+DVP+ZG*A1/2.+ZN/2./TER(MP,6,N))	PEST	861
GO TO 1626	PEST	862
C INTERPOLATION ESTIMATE OF PRESSURE IN SOLID	PEST	863
1625 PSJ = PSA+(DELV-DELVA)/(DELVB-DELVA)*(PSB-PSA)	PEST	864
1626 IF (PSJ .LT. PUP) PSJ = PUP+1.E7	PEST	865
IF (PSJ .GT. PL0) PSJ = PL0-1.E7	PEST	866
IF (NC .EQ. 1) GO TO 1627	PEST	867
IF (ABS(DELVA-DELV) .GT. ABS(DELVB-DELV)) GO TO 1623	PEST	868
1627 PSB = PSA \$ DELVB = DELVA	PEST	869
GO TO 1623	PEST	870
C CONCLUSION OF LOOP	PEST	871
1630 RVVL = (ZG+ZN)/VH \$ PTHL = PTHH \$ PSA=PS0=AMIN1(PTHH,AMAX1	PEST	872
1 (PELH,PSA))	PEST	873
VS0 = VH-ZG-ZN	PEST	874
ENT = ENT*VOLD/VH+TER(MP,4,N)*EXP(DP/2./TER(MP,6,N))*DTN	PEST	875
1632 CONTINUE	PEST	876
PJ = (1.-RVVL)*PSA	PEST	877
RVV = RVVL	PEST	878
1635 IF (RVV .GT. TER(MP,7,N)) GO TO 2000	PEST	879
GO TO 1900	PEST	880
C PROVISION FOR ABORT FOR ITERATION FAILURE	PEST	881
1640 NTRY = NTRY+1	PEST	882
IF (NTRY .GE. 5) GO TO 1643	PEST	883
VOLD = VH-DELV \$ DV = 1./D-VOLD	PEST	884
NLOOP = MAX1(3.,-2.**NTRY*DV*EQSTCM*D/AMIN1(PST,P)/ALF+0.8)	PEST	885
GO TO 1621	PEST	886
1643 WRITE(6,2349)M,P,DV,DELVA,DELVB	PEST	887
GO TO 1630	PEST	888
C BRITTLE FRACTURE AND FRAGMENTATION.	PEST	889
1660 GO TO 1900	PEST	890
C	PEST	891
C ** SOLID AND POROUS MELT AND SOLID BEHAVIOR	** C PEST	892
C	C PEST	893
1800 GO TO (1805,1810,1815) NPRM	PEST	894
1805 CALL EQST(E,D,PS,M,C,DPDDJ,DPDEJ)	PEST	895
GO TO 1840	PEST	896
1810 CALL ESA(1,5,M,C,D,E,PS,DPDDJ,DPDEJ)	PEST	897
GO TO 1840	PEST	898
1815 CALL EQSTPF(1,5,M,C,D,E,PS)	PEST	899
1840 IF (H .NE. 5R S) GO TO 1850	PEST	900

SUBROUTINE PEST (Concluded)

IF (F.EQ. 0.) GO TO 1850	PEST	901
PJ=PST=PEL=PS	PEST	902
GO TO 1860	PEST	903
1850 PJ = PST = PEL = AMAX1(0.,PS)	PEST	904
IF (PJ.GT. 0.) GO TO 1855	PEST	905
PTH = TSQE(1, PJ*RHOS/D, EQSTGM*RHOS*E, EQSTCM, EQSTDM, EQSTSM,	PEST	906
1 EQSTGM, EQSTHM, EQSTEM, RHOS, EQSTNM, E, EQSTVM, EQSTAM, NCYC)	PEST	907
RVV= AMAX1(0., 1. - D/PTH)	PEST	908
H = 5R M	PEST	909
GO TO 1860	PEST	910
1855 H=5R S \$ RVV=0.	PEST	911
1860 IF (PEL.LT. 0.) GO TO 1500	PEST	912
C	C PEST	913
C ** ENDING ROUTINE.	** C PEST	914
C	C PEST	915
IF (H.EQ. 5R M .OR. H.EQ. 5R S) GO TO 1905	PEST	916
1900 DPDDJ=DPDEJ=0.	PEST	917
1905 P=PJ	PEST	918
PST1=PST \$ AST1=ALFS	PEST	919
RETURN	PEST	920
C FRAGMENTATION.	PEST	921
2000 P=PST1=TJ=0.	PEST	922
RVV = -ABS(RVV)	PEST	923
AST1 = 1./((1.+RVV)	PEST	924
H = 5R Z	PEST	925
RETURN	PEST	926
2300 FORMAT(* D,BULK,MUM,C,F,ELK,ELG,RHOP1,E**1P9E10.3)	9/12/79	16
2349 FORMAT(* ITERATION FAILURE,M=*I2,* P=*1PE10.3,* DV=*1PE10.3,	PEST	928
1 * DELVA=*1PE10.3,* DELVB=*1PE10.3)	PEST	929
END	PEST	930

SUBROUTINE POREQST

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SUBROUTINE POREQST(NCALL,IN,M,C,D,DOLD,E,EOLD,F,P,CZJ,CWJ,H,DPDE, POREQST2
1 EQSTCM,EQSTDM,EQSTGM,EQSTSM,MUM,RHOSM,YADDM,NDSM,NPRM,J) POREQST3
C POREQST4
C ROUTINE READS INPUT DATA FOR POROUS MATERIAL AND COMPUTES PRESSURE POREQST5
C POREQST6
C READ INPUT (NCALL=0). CALL IS FROM GENRAT POREQST7
C INPUT - NCALL, IN, M, MATERIAL PROPERTY CARDS POREQST8
C OUTPUT - ORGANIZES DATA AND FILLS AK, MUP, PORA, RHOP, YADDP POREQST9
C PREPARE- D = RHOP(M,1), CZJ = CZQ(M) = COSQ(M,6) POREQST10
C YADDM = Y0(M), CWJ = CWQ(M) = C1(M,6) POREQST11
C C = EXMAT(M,3) = SOUND SPEED POREQST12
C COMPUTE PRESSURE (NCALL=1) POREQST13
C INPUT - NCALL,M,C,D,DOLD,E,EOLD,F,P=POLD,H,EQSTCM,EQSTGM,RHOSM, POREQST14
C NDSM,NPRM POREQST15
C OUTPUT - C,P,H,CZJ,CWJ,DPDE,MUM,YADDM POREQST16
C NOTE CHANGE IN INPUT SO THAT FIRST VALUE OF P2 IS YIELD AND POREQST17
C PERTAINS TO D .LE. RHOP(M,2) POREQST18
C POREQST19
REAL MUM,MUP POREQST20
INTEGER H POREQST21
COMMON /POR/ AK(6),MUP(6),NREG(6),PORA(6,5),PORB(6,5),PORC(6,5), POREQST22
1 RHOP(6,6),YADDP(6,5) POREQST23
DIMENSION COSQ(6,6),C1(6,6),TEMP(8) POREQST24
C POREQST25
DATA NAT,NBT,NCT,NDT,NET,NFT/10H -POREQST-,10H, ,G/CM3 , POREQST26
1 10H,G/CM3 ,10H,DYN/CM2,=,10H,DYN-CM/G ,10H,= / POREQST27
C POREQST28
IF (NCALL .EQ. 1) GO TO 200 POREQST29
C POREQST30
C **** READ INPUT DATA FOR POROUS MATERIAL **** POREQST31
C POREQST32
READ (IN,1192) A1,AK(M),A2,MUP(M),A3,YZERO POREQST33
PRINT 1130,A1,AK(M),A2,MUP(M),A3,YZERO,IN,NAT,NDT,NFT POREQST34
READ (IN,1100) A1,NREG(M) POREQST35
CJ=1. POREQST36
WRITE (6,1100) A1,NREG(M) POREQST37
WRITE(6,1110) IN,NAT,NBT POREQST38
READ (IN,1120) A1,(RHOP(M,I),I=1,6) POREQST39
PRINT 1131,A1,(RHOP(M,I),I=1,6),IN,NAT,NCT POREQST40
DO 50 I = 1,6 POREQST41
COSQ(M,I) = 4.0 POREQST42
50 C1(M,I) = 0.15 POREQST43
55 READ (IN,1005)(TEMP(I),I=1,8) POREQST44
DECODE (3,1125,TEMP) A1,A2 POREQST45
IF (A1 .EQ. 1HC .AND. (A2 .EQ. 1H0 .OR. A2 .EQ. 1H0)) GO TO 60 POREQST46
IF (A1 .EQ. 1HC .AND. A2 .EQ. 1H1) GO TO 62 POREQST47
GO TO 65 POREQST48
60 DECODE (80,1120,TEMP) A1,(COSQ(M,I),I=1,6) POREQST49
PRINT 1131,A1,(COSQ(M,I),I=1,6),IN,NAT POREQST50
GO TO 55 POREQST51
62 DECODE (80,1120,TEMP) A1,(C1(M,I),I=1,6) POREQST52
PRINT 1131,A1,(C1(M,I),I=1,6),IN,NAT POREQST53
GO TO 55 POREQST54
65 CZJ = COSQ(M,6) $ CWJ = C1(M,6) POREQST55
NP=NREG(M) $ P1=0. POREQST56
DECODE (80,1192,TEMP) A1,P1 POREQST57
PRINT 1132,A1,P1,IN,NAT,NDT POREQST58
PORA(M,1)=P1 $ PORB(M,1)=PORC(M,1)=0. POREQST59
YADDP(M,1)=0. POREQST60
DO 110 N = 1,NP POREQST61
READ (IN,1192) A1,P2,A2,DELP,A3,YADDP(M,N) POREQST62
PRINT 1130,A1,P2,A2,DELP,A3,YADDP(M,N),IN,NAT,NDT,NET POREQST63
DRHO=RHOP(M,N+1)-RHOP(M,N) POREQST64
PORA(M,N+1)=P1+RHOP(M,N+1)/DRHO*(P2-P1-4.*DELP*RHOP(M,N)/DRHO) POREQST65
PORB(M,N+1)=-RHOP(M,N+1)*RHOP(M,N)/DRHO*(P2-P1-4.*DELP*(RHOP(M,N+1) POREQST66
1 )+RHOP(M,N))/DRHO) POREQST67
PORC(M,N+1)=-4.*DELP*(RHOP(M,N+1)*RHOP(M,N)/DRHO)**2 POREQST68
110 P1=P2 POREQST69

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SUBROUTINE POREQST (Concluded)

170	YADDM = YZERU	POREQS70
	C = SQRT((AK(M) + 1.333 * MUP(M))/D)	POREQS71
190	RETURN	POREQS72
C		POREQS73
C	**** CALCULATION OF PRESSURE IN A POROUS MATERIAL ****	POREQS74
C		POREQS75
200	TF=1.+E*EQSTGM*RHOSM/EQSTCM \$ DREF=D*TF \$ NC=5	POREQS76
C	FIND APPROPRIATE DENSITY REGION OF POROUS RELATIONS	POREQS77
	IF (DREF .GT. RHOP(M,6)) GO TO 280	POREQS78
	P2 = 0.	POREQS79
	IF (DREF .GT. RHOP(M,5) .OR. H .EQ. 5R Q) GO TO 222	POREQS80
	NC=0	POREQS81
205	NC=NC+1	POREQS82
	IF (DREF .GT. RHOP(M,NC)) GO TO 205	POREQS83
	P2=F*(PORA(M,NC)+PORB(M,NC)/DREF+PORC(M,NC)/DREF**2)	POREQS84
	IF (DREF .LT. RHOSM) GO TO 230	POREQS85
C	CHECK FOR CONSOLIDATION IN LAST POROUS REGION	POREQS86
222	CALL EQST(E,D,PS,M,CJ,A1,A2)	POREQS87
	IF (H .EQ. 5R Q) GO TO 225	POREQS88
	IF (PS .LT. P2) GO TO 230	POREQS89
225	P=PS \$ H=5R Q \$ NC=5 \$ RETURN	POREQS90
C	COMPUTE PRESSURE ON INTERMEDIATE SURFACE	POREQS91
230	RHOM=RHOP(M,1)/TF \$ RHOPV=F*(RHOP(M,5)-RHOSM)+RHOSM/TF	POREQS92
	RATIO=AMIN1(1.,(RHOM-D)/(RHOM-RHOPV)*RHOPV/O*(1.-(RHOPV-D)/	POREQS93
1	(RHOPV-RHOM)*RHOM/D))	POREQS94
	BULK=F*(AK(M)+(EQSTCM-AK(M))*RATIO)	POREQS95
	MUM=F*MUP(M)+(MUM-MUP(M)*F)*RATIO	POREQS96
	PBULK=P+BULK*((D-DOLD)/(D+DOLD))+EQSTGM*RHOSM/EQSTCM*(E-EOLD)	POREQS97
C	CHECK WHETHER STATE POINT IS ON INTERMEDIATE OR YIELD SURFACE	POREQS98
	P=P2 \$ IF (PBULK .GT. P2) GO TO 250	POREQS99
	P=PBULK \$ IF (DREF .GT. RHOSM) P=AMAX1(PBULK,PS)	POREQ100
C	COMPUTE SOUND SPEED	POREQ101
250	CSQ=(BULK+1.333*MUM)/D	POREQ102
	IF (CSQ .LT. 0.) GO TO 270	POREQ103
	CQ=CSQ+C**2 \$ C=CSQ*C/CQ + 0.25*CQ/C \$ DPDE=0.	POREQ104
C	COMPUTE ARTIFICIAL VISCOSITY COEFFICIENTS	POREQ105
270	RATIO=0.	POREQ106
	DELR=RHOP(M,NC+1)-RHOP(M,NC)	POREQ107
	IF (DELR .NE. 0.) RATIO=(DREF-RHOP(M,NC))/DELR	POREQ108
	CZJ=COSQ(M,NC)+(COSQ(M,NC+1)-COSQ(M,NC))*RATIO	POREQ109
	CWJ=C1(M,NC)+(C1(M,NC+1)-C1(M,NC))*RATIO	POREQ110
	IF (NC .LE. NREG(M)) YADOM=YADDP(M,NC)	POREQ111
	RETURN	POREQ112
C	COMPUTE PRESSURE IN CONSOLIDATED MATERIAL	POREQ113
280	H=5R S	POREQ114
	CALL EQST(E,O,P,M,C,OPDO,DPDE)	POREQ115
1100	FORMAT(A10,I10,A10,1PE10.3)	POREQ116
1005	FORMAT(8A10)	POREQ117
1110	FORMAT(1H+,79X,7H IND= ,5H, IN=,I2,4A10)	POREQ118
1120	FORMAT(A10,7E10.3)	POREQ119
1125	FORMAT(1X,2A1)	POREQ120
1130	FORMAT(3(A10,1PE10.3),20X,7H IND= ,5H, IN=,I2,3A10)	POREQ121
1131	FORMAT(A10,1PE10.3,10X,7H IND= ,5H, IN=,I2,3A10)	POREQ122
1132	FORMAT(A10,1PE10.3,60X,12H IND= , IN=,I2,3A10)	POREQ123
1192	FORMAT(4(A10,E10.3))	POREQ124
	RETURN	POREQ125
	END	POREQ126

SUBROUTINE PORHOLT

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SUBROUTINE PORHOLT(NPART,IN,M,C,DH,DOLD,EH,EOLD,F,P,1H,J,DPDEJ,
1 EQSTCM,MUM,YADDM,RHOS,DT)
C
C      BASIC EQUATIONS OF THIS MODEL ARE BY AL HOLT OF LLL.
C
C      REAL MUM,MUP
C      DIMENSION RHO(6),RHOC(6),ALFO(6), AK(6),MUP(6),YADDP(6),PY(6),
1      Y0(6),ALF(300),A(6),B(6),RHOE(6),RHOES(6),TPH(6)
C
C      IF (NPART .EQ. 1) GO TO 200
C
C      ***** READ AND INITIALIZE *****
C
C      READ IN SPECIAL PROPERTIES FOR POROUS MATERIAL
C      WRITE (6,1010)
C      WRITE (6,1011)
C      READ (IN,1001) A1,RHO(M),A2,RHOC(M),A3,TPH(M),A4,PY(M)
C      WRITE (6,1001) A1,RHO(M),A2,RHOC(M),A3,TPH(M),A4,PY(M)
C      READ (IN,1001) A1,AK(M),A2,MUP(M),A3,Y0(M),A4,YADDP(M)
C      WRITE (6,1001) A1,AK(M),A2,MUP(M),A3,Y0(M),A4,YADDP(M)
C      READ (IN, 1001) A1,DPDRHO
C      WRITE (6,1001) A1,DPDRHO
C      INITIALIZE YIELD AND DENSITY FOR GENRAT
C      YADDM = Y0(M)
C      DH=RHO(M) $ C=SQRT((AK(M)+1.333*MUP(M))/DH)
C      INITIALIZE VARIABLES FOR PORHOLT
C      ALFO(M)=RHOS/RHO(M)
C      RHOE(M)=RHO(M)*(PY(M)/AK(M)+1.)
C      RHOES(M)=RHOS*(PY(M)/EQSTCM+1.)
C      ALFE=RHOES(M)/RHOE(M)
C      A(M)=ALFE*(ALFE*RHOE(M)/EQSTCM*DPDRHO-(RHOES(M)-RHOS)/RHOS)
C      B(M)=(RHOC(M)-RHOES(M))/(RHOC(M)-RHOE(M))*2-A(M)/(RHOC(M)-RHOE
1      (M))
C      PRINT 1002,A(M),B(M),RHOES(M),RHOE(M)
C      WRITE (6,1010)
C      CJ=1.
C      DO 150 I=1,300
150  ALF(I)=0.
C      RETURN
C
C      ***** COMPUTE PRESSURE *****
C
C      INITIALIZE ALF
200  CONTINUE
C      IF (ALF(J) .EQ. 0.) ALF(J)=ALFO(M)
C      IF (ALF(J) .LE. 1.) GO TO 300
C      COMPUTE ELASTIC VALUE OF ALF ON UNLOAD OR RELOAD CURVES
C      AAKC=(CURRENT BULK MODULUS)/(BULK MODULUS OF SOLID)
C      AAKC=AK(M)*(ALFO(M)-1.)/(AK(M)*(ALFO(M)-1.)+(EQSTCM-ALFO(M)*
1      AK(M))*(1.-1./ALF(J)))/ALF(J)
C      ALFE=ALF(J)*(DOLD/RHOS-P/EQSTCM)/(DH/RHOS-P/EQSTCM-AAKC*(DH-DOLD)/
1      RHO(M))
C      IF (DH .LT. DOLD) GO TO 250
C      COMPUTE STATIC VALUE OF ALF ON THE FLOW CURVE
C      ALFS=(RHOES(M)+(A(M)+B(M)*(DH-RHOE(M)))*(DH-RHOE(M)))/DH
C      CHECK WHETHER FLOW STRESS HAS BEEN REACHED DURING LOADING
C      IF (ALFS .GT. ALFE) GO TO 250
C      COMPUTE DYNAMIC VALUE OF ALF
C      ALF(J)=AMAX1(1.,(ALFS+TPH(M)*ALFE/DT)/(1.+TPH(M)/DT))
C      GO TO 255
250  ALF(J)=ALFE
C      COMPUTE DENSITY IN THE SOLID
255  DS=ALF(J)*DH
C      POLD=P
C      COMPUTE PRESSURE IN THE SOLID MATERIAL
C      CALL EQST(EH,DS,PS,M,CJ,DPDEJ)
C      COMPUTE GROSS PRESSURE
C      P=PS/ALF(J)

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SUBROUTINE PORHOLT (Concluded)

MUM=((ALFO(M)-ALF(M))*MUM+(ALF(J)-1.)*MUP(M))/(ALFO(M)-1.)	PORHOL70
YADDM=YADDP(M)	PORHOL71
CSQ=(AAKC*EQSTCM+1.333*MUM)/DH	PORHOL72
IF (CSQ .LT. 1.E6) GO TO 270	PORHOL73
C=SQRT(CSQ)	PORHOL74
270 RETURN	PORHOL75
C	PORHOL76
C ***** PRESSURE IN CONSOLIDATED MATERIAL *****	PORHOL77
C	PORHOL78
300 IH=5R S	PORHOL79
CALL EQST(EH,DH,P,M,C,DPDEJ)	PORHOL80
RETURN	PORHOL81
1001 FORMAT(4(A10,1PE10.3))	PORHOL82
1002 FORMAT(* A,B,RHOES,RHOE =*1P4E13.4)	PORHOL83
1010 FORMAT(/)	PORHOL84
1011 FORMAT(* READ IN PORHOLT*)	PORHOL85
END	PORHOL86

SUBROUTINE PRESR

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SUBROUTINE PRESR
INTEGER H,POROUS,PRESS,RINTER,SOLID,SPALL
REAL MATL,NEM,NET,NEMH,NETH
C MISCELLANEOUS
COMMON AZERO(1),CEF,CKS,DAVG,DELTIM,DISCPT(10),DOLD,DRHO,DTMAX,
1 DTMIN,DTN,DTNH,DU,DX,EOLD,F,FAC,FIRST,J,JCYCS,JINIT,
2 JFIN,JREZON(15),JSMAX,JSTAR,JTS,LSUB(30),M,MAXPR(30),N,NCYCS,
3 NEDIT,NPERN,NR,NREZON,NSCRB(6),NSEPHAT,NSPALL,NTEDT,
4 NTEX,NTR(15),POLD,P6(20),R(30),RLAST,SLAST,SMAX,TEDIT(50),
5 TF,TIME,TJ,TREZON,TS,T6(20),ULAST,UOLD,UZERO,XLAST,XNOW,XOLD
1 ,XJDDIT(20)
C HALFSTEP VALUES
COMMON DH,DHLAST,DUH,EH,PH,RH,RHLAST,SH,SHLAST,UH,UHLAST,XH,XHLAST
1 ,NEMH,NETH
C CONDITION INDICATORS
COMMON INF,LINTER,MIRROR,NORMAL,POROUS,PRESS,RINTER,SOLID,SPALL
C CELL LAYOUT
COMMON DXX(30),JBNU(30),JMAT(30),NAUTO,MATL(6,2),NLAYER,NMTRLS,
1 THK(30)
C COORDINATE ARRAYS
COMMON/COORD/X(200),X0(200),CHL(200),DHL(200),DPDD(200),DPDE(200),
1 EHL(200),H(200,3),NEM(200),NET(200),PHL(200),RHL(200),SDT(200),
2 SHL(200),T(200),U(200),YHL(200),ZHL(200)
COMMON /JED/JEDIT(100),JNUM(100),JTYP(100),NAME2(40),JEDSIZ,
1 MODLUS,NEER,NJEDIT,NTAPE
COMMON/NSC/A(5000)
DIMENSION NN(20),NAME(40),LA(1)
EQUIVALENCE (LA,A)
DATA (NAME(I),I=1,33)/3HX ,3HX0 ,3HC ,3HD ,4HDPDD,4HDPDE,3HE ,
1 3HH1 ,3HH2 ,3HH3 ,3HNEM,3HNET,3HP ,3HR ,3HSDT,3HS1 ,3HT ,3HU
2 ,3HY ,3HZ ,4HCOM1,4HCOM2,4HCOM3,4HCOM4,4HCOM5,5HS-INT,3HS2 ,
3 3HS3 , 3HIMP,3HV ,3HSD1,3HSD2,3HSO3/
DATA (NAME2(1),I=1,33)/1RX,2RX0,1RC,1RD,4RDPDD,4RDPDE,1RE,2RH1,
1 2RH2,2RH3,3RNEM,3RNET,1RP,1RR,3RSDT,2RS1,1RT,1RU,
2 1RY,1RZ,4RCOM1,4RCOM2,4RCOM3,4RCOM4,4RCOM5,5RS-INT,2RS2,2RS3,
3 3RIMP,1RV,3RSD1,3RSD2,3RSD3/
C JK FIRST CARD OF A(100+ ) TO BE READ FROM
C JF FIRST WORD OF A( ) TO BE READ INTO
C KB,KE BEGINNING AND ENDING VALUE J FOR GROUP
C JE COUNTER FOR JEDITS
C JFIRST FIRST JEDIT OF A GROUP
C JTLAST INDICATOR THAT THE PREVIOUS GROUP WAS ALPHA (=0) OR
C INTEGER (=1)
C K CHARACTER COUNTER
C JKMAX NUMBER OF CHARACTERS USED AT A TIME
C NCARD NUMBER OF RECORDS DECODED
C 1W COUNTER FOR ALPHA GROUPS
C K COUNTER FOR CHARACTERS ON A CARD
C KP PERIOD INDICATOR
C JTYP( ) TITLE ARRAY FOR HEADINGS IN SCRIBE
C JNUMC( ) LOCATION IN ARRAY COMMON
C JEDIT( ) J(CELL OR COORDINATE) NUMBER
NJD=1ABS(NJEDIT)
IF (NJEDIT .LT. 0) NJD=(-NJEDIT-1)/14+1
JK=1
NLAY1=NLAYER+1
DO 50 I=1,NLAY1
JEDIT(1)=I
JTYP(1)=5HS-INT
50 JNUM(1)=5000
60 NLL=0
IF (H(1,2) .EQ. SPALL) GO TO 70
NLL=NLL+1
JEDIT(NLAYER)=0
70 IF (H(JFIN,2) .EQ. SPALL) GO TO 75
JEDIT(NLAYER+NLL)=NLAYER
NLL=NLL+1

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SUBROUTINE PRESCR (Continued)

75	JE=N_LAYER+NLL	PRESR48
	JFIRST=N_LAYER+NLL	PRESR49
	JTLAST=0	PRESR50
	AB=1H	PRESR51
	NCARD=0	PRESR52
	K=1	PRESR53
	KB=1	PRESR54
	JKMAX=70	PRESR55
	JF=1	PRESR56
	IW=1	PRESR57
C		PRESR58
C	SELECT A GROUP OF CHARACTERS	PRESR59
80	DECODE (80,1024,A(4000+JK))(A(L),L=JF,JKMAX)	PRESR60
	JF1=JF-1	PRESR61
	JK1=4000+JK-1	PRESR62
	KP=0	PRESR63
	NCARD=NCARD+1	PRESR64
100	IF (K.GT. JKMAX) GO TO 300	PRESR65
	IF (LA(K).EQ. 1H) GO TO 150	PRESR66
	IF ((LA(K).GE. 1HA.AND. LA(K).LE. 1HZ).OR.	PRESR67
1	LA(K).GE. 1H0.AND. LA(K).LE. 1H9)) GO TO 140	PRESR68
	IF (LA(K).NE. 1H.) GO TO 150	PRESR69
	KP=K	PRESR70
140	K=K+1	PRESR71
	IF (K.GT. JKMAX) GO TO 160	PRESR72
	GO TO 100	PRESR73
150	IF (KB.LT. K) GO TO 160	PRESR74
	KB=KB+1	PRESR75
	K=K+1	PRESR76
	GO TO 100	PRESR77
160	KE=K-1	PRESR78
C		PRESR79
C	EXAMINE A GROUP OF CHARACTERS FOR TYPE	PRESR80
	NK=KE-KB+1	PRESR81
	NNL=KP-KB	PRESR82
	JFR=KE	PRESR83
	IF (KP.NE. 0) GO TO 220	PRESR84
	IF (A(KB).GE. 1HA.AND. A(KB).LE. 1HZ) GO TO 180	PRESR85
C	INTEGER DATA	PRESR86
	KN=10-NK	PRESR87
	ENCODE(10,1021,A1)(AB,L=1,KN),(A(L),L=KB,KE)	PRESR88
	DECODE (10,1020,A1) JEDIT(JE)	PRESR89
	IF (JE.NE. N_LAYER.OR. IW.NE. 1) GO TO 175	PRESR90
	NN(IW)=2HS1	PRESR91
	IW=IW+1	PRESR92
175	JTLAST=1	PRESR93
	JE=JE+1	PRESR94
	GO TO 260	PRESR95
C	ALPHABETIC DATA	PRESR96
180	IF (JTLAST.EQ. 0) GO TO 210	PRESR97
C	SET TYPE INDICATORS FOR ALL JEDITS OF A SET AFTER THE NEXT	PRESR98
C	ALPHA GROUP HAS OCCURRED	PRESR99
	JE=JE-1	PRESR100
	NDJ=0	PRESR101
	IW1=IW-1	PRESR102
	NDJ=-(JE-JFIRST+1)	PRESR103
	DO 205 I=1,IW1	PRESR104
C		PRESR105
C	CHECK LEGITIMACY OF ALPHA DATA	PRESR106
	IF ((NN(I).AND. 77777700000000000000B).EQ. 3LCOM) GO TO 190	PRESR107
	DO 185 IK=1,33	PRESR108
	IF (NN(I).EQ. NAME(IK)) GO TO 190	PRESR109
185	CONTINUE	PRESR110
	GO TO 205	PRESR111
190	NDJ=JE-JFIRST+1+NDJ	PRESR112
	DO 200 J=JFIRST,JE	PRESR113
	JTYP(J+NDJ)=NN(I)	PRESR114
	IF (I.EQ. 1) GO TO 200	PRESR115
	JEDIT(J+NDJ)=JEDIT(J)	PRESR116

SUBROUTINE PRESCR (Continued)

200	CONTINUE	PRESC117
205	CONTINUE	PRESC118
	JE=JFIRST=JE+NDJ+1	PRESC119
	JTLAST=0	PRESC120
	Iw=1	PRESC121
C	DECODE THE ALPHA GROUP OF A SET	PRESC122
210	ENCOOE (NK,1021,NN(IW))(A(L),L=KB,KE)	PRESC123
	Iw=IW+1	PRESC124
	GO TO 260	PRESC125
C	JEOIT LISTED AS LAYER AND FRACTION	PRESC126
220	NNL=KP-KB	PRESC127
	JFR=KE-KP+1	PRESC128
	KP1=KP-1	PRESC129
	KN=10-NNL	PRESC130
	ENCOOE (10,1021,A1) (AB,L=1,KN), (A(L),L=KB,KP1)	PRESC131
	DECODE (10,1020,A1) NL	PRESC132
	ENCOOE (JFR,1021,A1) (A(L),L=KP,KE)	PRESC133
	DECOOE (10,1025,A1) FR	PRESC134
	JEND=JBNO(NL)	PRESC135
	JBEG=1	PRESC136
	IF (NL .GT. 1) JBEG=JBND(NL-1)+1	PRESC137
	OIST=X(JBEG)+FR*(X(JENO)-X(JBEG))	PRESC138
	J=JBEG	PRESC139
240	J=J+1	PRESC140
	IF (X(J) .LT. OIST) GO TO 240	PRESC141
	JEDIT(JE)=J-1	PRESC142
	JE=JE+1	PRESC143
	JTLAST=1	PRESC144
260	CONTINUE	PRESC145
	K=KB=K+1	PRESC146
	KP=0	PRESC147
	GO TO 100	PRESC148
C		PRESC149
C	PREPARE FOR NEXT CARD OF DATA	PRESC150
300	IF (NCARD .GE. NJD) GO TO 400	PRESC151
	JF=1	PRESC152
	JK=1+8*NCARD	PRESC153
	JKMAX=70	PRESC154
	KDIF=K-KB	PRESC155
	IF (KB .EQ. K) GO TO 330	PRESC156
	KB1=KB-1	PRESC157
	KDIF1=KOIF+1	PRESC158
	DO 320 KK=1,KDIF1	PRESC159
320	A(KK)=A(KB1+KK)	PRESC160
	JF=1+KDIF1	PRESC161
	JKMAX=70+KDIF+1	PRESC162
	KB=1	PRESC163
	K=KB+KDIF+1	PRESC164
	GO TO 80	PRESC165
330	KB=K=1	PRESC166
	GO TO 80	PRESC167
400	CONTINUE	PRESC168
	JE=JE-1	PRESC169
	NDJ=0	PRESC170
	Iw1=IW-1	PRESC171
	DO 420 I=1,IW1	PRESC172
	NDJ=(JE-JFIRST+1)*(I-1)	PRESC173
	DO 420 J=JFIRST,JE	PRESC174
	JTYP(J+NDJ)=NN(I)	PRESC175
	IF (I .EQ. 1) GO TO 420	PRESC176
	JEDIT(J+NDJ)=JEDIT(J)	PRESC177
420	CONTINUE	PRESC178
	NJEOIT=JE+NDJ	PRESC179
C	PRINT AND PUNCH JEDIT VALUES	PRESC180
	JFIRST=1	PRESC181
	IENO=0	PRESC182
	JTYPE=JTYP(1)	PRESC183
	DO 450 J=2,NJEDIT	PRESC184

SUBROUTINE REBAR

	SUBROUTINE REBAR(LL,IN,JC,IC,M,N,IH,DH,DOLD,SX,SY,SZ,TTY,E,P,	REBAR	2
	1 DEX,DEY,DEZ,DEXY,F,THETA,DTHETA,ESC,FS,DSTL,SRS,	REBAR	3
	2 ZEVP,TEVP,Y,ROLD,IPRINT)	REBAR	4
C	SR1 AND SR3 ARE OLD AND NEW STRESSES ON STEEL.	REBAR	5
C	SR2 AND SR4 ARE OLD AND NEW STRESSES ON CONCRETE.	REBAR	6
C	ALL STRESSES ARE DEVIATORS EXCEPT SRS ARRAY	REBAR	7
C	STRESSES ARE POSITIVE IN TENSION, PRESSURE IS POSITIVE IN COMP.	REBAR	8
C	STRAINS ARE POSITIVE IN TENSION	REBAR	9
C	PLANE OF REBARS IS INITIALLY NORMAL TO THE X DIRECTION	REBAR	10
C	THETA IS OLD VALUE OF ROTATION ANGLE, POSITIVE TOWARDS Y	REBAR	11
C	DTHETA IS INCREMENT OF THETA ON CURRENT CYCLE	REBAR	12
	DIMENSION SR(4),SRS(4),SR1(4),SR2(4),DEC(4),DES(4),SR3(4),	REBAR	13
	1 SR4(4),THET(6),IMC(6),IMS(6),FSTEEL(6),ESC(6,20)	REBAR	14
	IF (LL .GE. 0) GO TO 15	REBAR	15
	READ 1004,A1,FSTEEL(M),A2,THET(M),A3,IMC(M),A4,IMS(M)	REBAR	16
	PRINT 1004,A1,FSTEEL(M),A2,THET(M),A3,IMC(M),A4,IMS(M)	REBAR	17
1004	FORMAT(A10,E10.3,A10,E10.3,A10,I10,A10,I10)	REBAR	18
	LS=0	REBAR	19
	MC=IMC(M)	REBAR	20
	MS=IMS(M)	REBAR	21
	SX=SQRT((FSTEEL(M)*(ESC(MS,2)+1.33*ESC(MS,5))+(1.-FSTEEL(M))*	REBAR	22
	1 (ESC(MC,2)+1.33*ESC(MC,5)))/(FSTEEL(M)*ESC(MS,1)+(1.-FSTEEL(M))*	REBAR	23
	2 ESC(MC,1)))	REBAR	24
	DH=FSTEEL(M)*ESC(MS,1)+(1.-FSTEEL(M))*ESC(MC,1)	REBAR	25
	Y=ESC(MS,10)	REBAR	26
	RETURN	REBAR	27
15	IF(ROLD .NE. 0.) GO TO 18	REBAR	28
	MC=IMC(M)	REBAR	29
	MS=IMS(M)	REBAR	30
	FS=FSTEEL(M)	REBAR	31
	THETA=THET(M)	REBAR	32
	DSTL=ESC(MS,1)	REBAR	33
	ROLD=ESC(MC,1)	REBAR	34
18	CONTINUE	REBAR	35
	MC=IMC(M) \$ MS=IMS(M)	REBAR	36
	NTRY=1	REBAR	37
	RHOS=ESC(MC,7)	REBAR	38
	EQSTC=ESC(MC,2)	REBAR	39
	GRUN=ESC(MC,9)	REBAR	40
	AMU=ESC(MC,5)	REBAR	41
	CRIT=1.E7	REBAR	42
	TEVPSV=TEVP	REBAR	43
	ZEVP=ZEVP	REBAR	44
	YSV=Y	REBAR	45
	IHSV=IH	REBAR	46
	IPRINT=0	REBAR	47
	FS1=FS=(DOLD-ROLD)/(DSTL-ROLD)	REBAR	48
	COS2TH=COS(2.*THETA)	REBAR	49
	SIN2TH=SIN(2.*THETA)	REBAR	50
C	ROTATE STRAIN INCREMENTS TO AXIS OF REBARS	REBAR	51
	SIN2TH1=SIN2TH+DTHETA*COS2TH \$ COS2TH1=COS2TH-SIN2TH*DTHETA	REBAR	52
	DE(1)=(DEX+DEY+(DEX-DEY)*COS2TH1)/2.+DEXY*SIN2TH1	REBAR	53
	DE(2)=(DEX+DEY-(DEX-DEY)*COS2TH1)/2.-DEXY*SIN2TH1	REBAR	54
	DE(3)=DEZ	REBAR	55
	DE(4)=-(DEX-DEY)*SIN2TH1/2.+DEXY*COS2TH1	REBAR	56
C	ROTATE STRESSES TO AXIS OF REBARS	REBAR	57
	SR(1)=(SX+SY+(SX-SY)*COS2TH)/2.+TTY*SIN2TH	REBAR	58
	SR(2)=(SX+SY-(SX-SY)*COS2TH)/2.-TTY*SIN2TH	REBAR	59
	SR(3)=SZ	REBAR	60
	SR(4)=-(SX-SY)*SIN2TH/2.+TTY*COS2TH	REBAR	61
	RL=0. \$ RR=1.	REBAR	62
	IF (IPRINT .EQ. 1) PRINT 1120,(SR(I),I=1,4),SX,SY,SZ,TTY,COS2TH,	REBAR	63
	1 SIN2TH	REBAR	64
C	*****	REBAR	65
C	BEGINNING OF COMPUTATIONAL LOOP FOR EACH STRAIN INCREMENT	REBAR	66
120	PS=PS1=-(SRS(1)+SRS(2)+SRS(3))/3.	REBAR	67
	FS=FS1	REBAR	68
	PC=PC1=(P-PS1*FS)/(1.-FS)	REBAR	69
	DO 170 I=1,4	REBAR	70
	SR1(I)=SRS(I)+PS1	REBAR	71
	IF (I .EQ. 4) SR1(4)=SRS(4)	REBAR	72
	SR2(I)=(SR(I)-SR1(I)*FS)/(1.-FS)	REBAR	73
170	DEC(I)=DES(I)=DE(I)*RR	REBAR	74
	DES(I)=DEC(I)*ESC(MC,2)/ESC(MS,2)	REBAR	75
	DEC(I)=(DE(I)*RR-DES(I)*FS)/(1.-FS)	REBAR	76

SUBROUTINE REBAR (Continued)

180	NC=0	REBAR	77
C	*****	*****	REBAR
C	BEGINNING OF ITERATION LOOP	REBAR	78
200	NC=NC+1	REBAR	79
	DO 210 I=1,4	REBAR	80
	SR3(I)=SR1(I)	REBAR	81
210	SR4(I)=SR2(I)	REBAR	82
	TEVP=TEVPSV	REBAR	83
	ZEVP=ZEVPSV	REBAR	84
	Y=YSV	REBAR	85
	IH=IHSV	REBAR	86
	PS=PS1 \$ PC=PC1	REBAR	87
	RX=SR4(1)-PC \$ RY=SR4(2)-PC \$ RZ=SR4(3)-PC \$ RXY=SR4(4)	REBAR	88
	DEST=(DEC(1)+DEC(2)+DEC(3))/3.	REBAR	89
	RH=ROLD*(2.-DEST)/(2.+DEST)	REBAR	90
	IF (IPRINT .EQ. 1) PRINT 1002,RH,ROLD,RX,RY,RZ,RXY,ZEVP,TEVP	REBAR	91
	CALL CAP1(LS,IN,MC,N,IH,RH,ROLD,E,DEC(1),DEC(2),DEC(3),DEC(4),	REBAR	92
1	RX,RY,RZ,RXY,ZEVP,IC,JC,TEVP)	REBAR	93
	IF (IPRINT .EQ. 1) PRINT 1003,RH,ROLD,RX,RY,RZ,RXY,ZEVP,TEVP	7/31/79	155
	PC=-(RX+RY+RZ)/3.	REBAR	95
	SR4(1)=RX+PC \$ SR4(2)=RY+PC \$ SR4(3)=RZ+PC \$ SR4(4)=RXY	REBAR	96
	DEST=(DES(1)+DES(2)+DES(3))/3.	REBAR	97
	D=DSTL*(2.-DEST)/(2.+DEST)	REBAR	98
	CALL EPLAS(JC,IC,MS,SR3,PS,DES,ESC,D,Y)	REBAR	99
	SCTEST= SR4(1)-PC \$ STEST = SR3(1)-PS	REBAR	100
	IF (IPRINT .EQ. 1) PRINT 1001,NC,DES(1),DEC(1),PC,PS,(SR1(I),I=1,4	REBAR	101
1	), (SR2(I),I=1,4), (SR3(I),I=1,4), (SR4(I),I=1,4), SCTEST, STEST	REBAR	102
	IF (ABS(SR4(1)-PC-SR3(1)+PS) .LT. CRIT) GO TO 290	REBAR	103
	DEZA=DES(1) \$ DSZA=SR4(1)-SR3(1) -PC+PS	REBAR	104
	IF (NC .EQ. 1) GO TO 250	REBAR	105
	IF (NC .LT. 12) GO TO 260	REBAR	106
	IF (NTRY .LT. 5) GO TO 450	REBAR	107
C	ABORT PROVISION	REBAR	108
	PRINT 1240,JC,IC,N,PS,PC,SSTEST,SCTEST,SR1,SR2,SR3,SR4,DES,DEC	REBAR	109
1240	FORMAT(1X,* ABORT IN REBAR FOR NTRY EQUALS 5 FOR J=*,I5,* I=*,I5,	REBAR	110
1	* ON CYCLE *,I5,/,1X,* PS=*,E10.3,* PC=*,E10.3,* STEST=*,E10.3,	REBAR	111
2	* SCTEST=*,E10.3,/,* SR1=*,4E10.3,/,* SR2=*,4E10.3,/,* SR3=*,4E10.3,	REBAR	112
3	* SR4=*,4E10.3,/,* DES=*,4E10.3,* DEC=*,4E10.3)	REBAR	113
	GO TO 320	REBAR	114
C	PREPARATION FOR SECOND ITERATION	REBAR	115
250	DES(1)=DES(1)+(SR4(1)-PC-SR3(1)+PS)/(ESC(MC,2)*FS/(1.-FS)+ESC(MS,2	REBAR	116
1	))	REBAR	117
	DEC(1)=(DE(1)*RR -DES(1)*FS)/(1.-FS)	REBAR	118
	GO TO 280	REBAR	119
C	REGULA FALSI BRANCHES	REBAR	120
260	IF (NC .EQ. 2) GO TO 262	REBAR	121
	IF (DSZC .GT. 0.) GO TO 265	REBAR	122
	IF (DSZB .LT. 0.) GO TO 262	REBAR	123
	IF (DSZA .GT. 0.) GO TO 265	REBAR	124
262	DES(1)=DEZA+(DEZB-DEZA)/(DSZB-DSZA)*(-DSZA)	REBAR	125
	IF (NC .EQ. 6 .OR. NC .EQ. 10) DES(1)=0.5*(DEZA+DEZB)	REBAR	126
	GO TO 270	REBAR	127
265	DES(1)=DEZA+(DEZC-DEZA)/(DSZC-DSZA)*(-DSZA)	REBAR	128
	IF (NC .EQ. 6 .OR. NC .EQ. 10) DES(1)=0.5*(DEZA+DEZC)	REBAR	129
270	DEC(1)=(DE(1)*RR -DES(1)*FS)/(1.-FS)	REBAR	130
	IF (NC .GT. 2) GO TO 275	REBAR	131
	IF (DSZA .LT. DSZB) 283,279	REBAR	132
275	IF (DSZA .GT. DSZB .OR. DSZA .LT. DSZC) GO TO 277	REBAR	133
	IF (DSZA .LT. 0.) 283,280	REBAR	134
277	IF (DSZB .LT. 0. .AND. DSZA .GT. DSZB) GO TO 279	REBAR	135
	IF (DSZC .GT. 0. .AND. DSZA .GT. DSZC) 282,200	REBAR	136
279	DSZC=DSZB \$ DEZC=DEZB	REBAR	137
280	DSZB=DSZA \$ DEZB=DEZA \$ GO TO 200	REBAR	138
282	DSZB=DSZC \$ DEZB=DEZC	REBAR	139
283	DSZC=DSZA \$ DEZC=DEZA \$ GO TO 200	REBAR	140
C	*****	*****	REBAR
C	END OF ITERATION LOOP, RESET FOR NEXT STRAIN INCREMENT	REBAR	141
290	DO 295 I=1,4	REBAR	142
	SR1(I)=SR3(I)	REBAR	143
295	SR2(I)=SR4(I)	REBAR	144
	IHSV=IH	REBAR	145
	YSV=Y	REBAR	146
	TEVPSV=TEVP	REBAR	147
	ZEVPSV=ZEVP	REBAR	148
	FS=FS*(1.+DES(1))/(FS*(1.+DES(1))+(1.-FS)*(1.+DEC(1)))	REBAR	149
		REBAR	150
		REBAR	151

SUBROUTINE REBAR (Concluded)

	DSTL=D	REBAR	152
	ROLD=RH	REBAR	153
	PS1=PS \$ PC1=PC	REBAR	154
	RL=RL+RR	REBAR	155
	IF (RL .LT. .999) GO TO 180	REBAR	156
C	ENDING ROUTINE	REBAR	157
320	CONTINUE	REBAR	158
	DO 330 I=1,4	REBAR	159
	SR(I)=SR4(I)*(1.-FS)+SR3(I)*FS	REBAR	160
330	SRS(I)=SR3(I)-PS	REBAR	161
	SRS(4)=SR3(4)	REBAR	162
	THETA2=(THETA+DTHETA)*2.	REBAR	163
	SIN2TH1=SIN(THETA2) \$ COS2TH1=COS(THETA2)	REBAR	164
	SX=(SR(1)+SR(2)+(SR(1)-SR(2))*COS2TH1)/2.-SR(4)*SIN2TH1	REBAR	165
	SY=(SR(1)+SR(2)-(SR(1)-SR(2))*COS2TH1)/2.+SR(4)*SIN2TH1	REBAR	166
	SZ=SR(3)	REBAR	167
	TXY=+(SR(1)-SR(2))/2.*SIN2TH1+SR(4)*COS2TH1	REBAR	168
	IF (IPRINT .EQ. 1) PRINT 1120,(SR(I),I=1,4),SX,SY,SZ,TXY,COS2TH1,	REBAR	169
	1 SIN2TH1	REBAR	170
	P=PC*(1.-FS)+PS*FS	REBAR	171
	RETURN	REBAR	172
C	PROVISION TO CUT STRAIN INCREMENTS	REBAR	173
450	NTRY=NTRY+1	REBAR	174
	IF (NTRY .EQ. 5) IPRINT=1	REBAR	175
	RR=RR/3.	REBAR	176
	GO TO 120	REBAR	177
1001	FORMAT(1X,* NC=*15,* DES(1),DEC(1)=*, 1P2E10.3,* PC=*,E10.3,* PS=*	REBAR	178
	1,E10.3,/,1X,* SR1=*,4E10.3,* SR2=*,4E10.3,/,1X,* SR3=*,4E10.3,	REBAR	179
	2* SR4=*,4E10.3/,1X,* (CONCRETE STRESS) SR4(1)-PC=*,E12.5,* (STEEL	REBAR	180
	3STRESS) SR3(1)-PS=*,E12.5)	REBAR	181
1002	FORMAT(* BEFORE CAP,RH,ROLD=*1P2E10.3,	REBAR	182
	1 * RX,RY,RZ,RXY=*4E10.3,* ZEVP,TEVP=*2E10.3)	REBAR	183
1003	FORMAT (* AFTER CAP, RH,ROLD=*1P2E10.3,	REBAR	184
	1 * RX,RY,RZ,RXY=*4E10.3,* ZEVP,TEVP=*2E10.3)	REBAR	185
1120	FORMAT(* SR1,SR2,SR3,SR4=*4E10.3/* SX,SY,SZ,TXY=*4E10.3/* COS2TH,	REBAR	186
	1 SIN2TH=*2E10.3)	REBAR	187
	END	REBAR	188

SUBROUTINE REDR

	SUBROUTINE REDR(NA,NB,IN,NO)	REDR	2
C	TO PREPARE TAPE4 FOR READING, COPY FROM INPUT TO TAPE4 WITH THE	REDR	3
C	COMMAND - - COPYCR(INPUT,TAPE4)	REDR	4
C	THE INPUT CARDS SHOULD BE IN NORMAL FORM FOR MATERIALS INPUT,	REDR	5
C	WITH BLANKS IN FIRST COLUMN. THE INPUT CARDS ARE BETWEEN 789	REDR	6
C	CARDS BUT THERE ARE NO SEPARATORS BETWEEN MATERIALS.	REDR	7
	REWIND IN	REDR	8
	NN=0	REDR	9
	IDD=1H	REDR	10
10	READ (IN,100) IND,NAA,NBB	REDR	11
	NN=NN+1	REDR	12
	IF (EDF(IN)) 15,20	REDR	13
15	PRINT 110,IDD,NA,NB,IND,NAA,NBB	REDR	14
	STOP 2254	REDR	15
20	IF (NA.NE.NAA .OR. (NB.NE.NBB .AND. NO.EQ.2)) GO TO 10	REDR	16
	REWIND IN	REDR	17
	NN=NN-1	REDR	18
	IF (NN .EQ. 0) RETURN	REDR	19
	DD 40 N=1,NN	REDR	20
	READ (IN,100) IND	REDR	21
40	CONTINUE	REDR	22
	RETURN	REDR	23
100	FORMAT (A1,A9,A10)	REDR	24
110	FORMAT (15H SEARCHING FOR A1,A9,A10,8H, FOUND A1,A9,A10)	REDR	25
	END	REDR	26

SUBROUTINE RELAX

	SUBROUTINE RELAX (ICON,SD,Y2,DRO,COEF,N,J,M,ANM,ANT,DT,TSR,YD,	RELAX 2
	1 Y1,INSR)	RELAX 3
C		RELAX 4
C	CALL BY HSTRESS TO COMPUTE DEVIATOR STRESS ACCORDING TO	RELAX 5
C	STANDARD ANELASTIC AND TWO-PARAMETER YIELD MODELS, NDS=1 AND 4.	RELAX 6
C	INPUT - ALL FORMAL PARAMETERS	RELAX 7
C	OUTPUT - SD, ICON, YOLD=YNEW.	RELAX 8
C		RELAX 9
	DIMENSION TSR(6,30)	RELAX 10
	YOLD = 0.6667*Y2	RELAX 11
	YAD = 0.6667*YD	RELAX 12
	YNOT = 0.6667*Y1	RELAX 13
C		RELAX 14
	TRLX=TSR(M,15) \$ TY=TSR(M,16) \$ SDO=SD \$ ICOR=ICON	RELAX 15
	YNEW=YOLD \$ L=0	RELAX 16
	IN=MAX0(2,INSR)/2	RELAX 17
	IF (ICON.EQ. 2) 18,2	RELAX 18
C	INITIAL CONDITION OUTSIDE OF ELASTIC ZONE	RELAX 19
2	L=1 \$ GO TO (4,3)IN	RELAX 20
3	XPY=EXP(-DT/TY)	RELAX 21
	YNEW=YNOT+(YOLD-YNOT)*XPY+ABS(COEF)*TY/DT*(1.-XPY)*.5*(1.+SIGN(1.,	RELAX 22
	IDRO)*SIGN(1.,SDO))	RELAX 23
	YAVG = (YNEW+YOLD)/2. \$ YSTAR = SIGN(YAVG,SDO) \$ GO TO 5	RELAX 24
4	YSTAR = SIGN(YOLD,SDO)	RELAX 25
5	XPO=EXP(-DT/TRLX)	RELAX 26
	SD = YSTAR + (SDO-YSTAR)*XPO + COEF*TRLX/DT*(1.-XPO)	RELAX 27
C	CHECK IF DEVIATOR CROSSES INTO ELASTIC ZONE. IF SO, RECALCULATE	RELAX 28
	IF (ABS(SD).GE.YNEW.AND.SIGN(1.,SD).EQ.SIGN(1.,SDO)) 30,6	RELAX 29
6	TC = (SIGN(YNEW,SDO)-SDO)/(SD-SDO)*DT \$ L=2	RELAX 30
	GO TO (9,7)IN	RELAX 31
7	YNEW=YNOT+(YOLD-YNOT)*EXP(-TC/TY)	RELAX 32
	YAVG = (YNEW+YOLD)/2. \$ YSTAR = SIGN(YAVG,SDO)	RELAX 33
9	XPO = EXP(-TC/TRLX)	RELAX 34
	SD=YSTAR+(SDO-YSTAR)*XPO+COEF*TRLX/DT*(1.-XPO)+COEF*(DT-TC)/DT	RELAX 35
C	CHECK IF DEVIATOR CROSSES OVER INTO OTHER SIDE OF ZONE	RELAX 36
	IF (ABS(SD).GT.YNEW) 11,10	RELAX 37
10	ICON = 2 \$ L=3 \$ GO TO 35	RELAX 38
11	IF (SIGN(1.,SD).EQ.SIGN(1.,SDO)) 30,12	RELAX 39
C	RECALCULATE TIME DURING WHICH RELAXATION OCCURS	RELAX 40
12	TK = (SD+SIGN(YNEW,SDO))/(SD-SIGN(YNEW,SDO))*(DT-TC) \$ L=4	RELAX 41
	GO TO (25,13)IN	RELAX 42
13	XPY=EXP(-TK/TY)	RELAX 43
	YNEW=YNOT+(YNEW-YNOT)*XPY+ABS(COEF)*TY/DT*(1.-XPY)	RELAX 44
	YAVG = (YNEW+YOLD)/2. \$ YSTAR = SIGN(YAVG,SD) \$ GO TO 25	RELAX 45
C	NOW CONSIDER INITIAL CONDITIONS INSIDE ELASTIC ZONE	RELAX 46
18	SD = SDO + COEF	RELAX 47
C	CHECK IF DEVIATOR CROSSES ZONE BOUNDARY	RELAX 48
	IF (ABS(SD).GT.YOLD) 19,35	RELAX 49
C	CHANGE CONDITION VARIABLE AND RECALCULATE DEVIATOR WITH RELAXATION	RELAX 50
19	YSTAR = SIGN(YOLD,SD) \$ L=5 \$ TK=(SD-YSTAR)/(SD-SDO)*DT	RELAX 51
	GO TO (25,20)IN	RELAX 52
20	YNEW=YNOT+ABS(COEF)*TY/DT*(1.-EXP(-TK/TY))	RELAX 53
	YAVG = (YNEW+YNOT)/2. \$ YSTAR = SIGN(YAVG,SD)	RELAX 54
25	ICON = 2 - IFIX(SIGN(1.,SD))	RELAX 55
	SD = YSTAR + COEF*TRLX/DT*(1-EXP(-TK/TRLX))	RELAX 56
30	GO TO (31,35)IN	RELAX 57
C	RECALCULATE YIELD STRENGTH TO ACCOUNT FOR STRAIN HARDENING	RELAX 58
31	YNEW = AMIN1(AMAX1(ABS(SD),YOLD),YOLD+YAD*ABS(DRO))	RELAX 59
	IF (YNEW.EQ.ABS(SD)) 32,35	RELAX 60
32	ICON=2 \$ L=L+10	RELAX 61
35	CONTINUE	RELAX 62
	Y2 = 1.5* YNEW	RELAX 63
	RETURN	RELAX 64
	END	RELAX 65

SUBROUTINE REZONE

	SUBROUTINE REZONE	REZONE	2
C		REZONE	3
C	INCREASES CELL SIZES TO GIVE MORE UNIFORM DISTRIBUTION	REZONE	4
C	* STARTS REZONING AT JREZON AND WORKS TOWARD JINIT	REZONE	5
C	* DOES NOT DISTURB LOCATION OF INTERFACES, JEDITS, OR SPALLS	REZONE	6
C		REZONE	7
C	INPUT - NREZON, SSTOPM.	REZONE	8
C	OUTPUT - ARRAY VARIABLES X, C, CHL, D, DHL, EHL, H, NEM, NET, P, P	REZONE	9
C	R, S, SHL, T, U, UHL, YHL, ZHL, AND JEDIT, JBND.	REZONE	10
C		REZONE	11
	INTEGER H, POROUS, PRESS, RINTER, SOLID, SPALL	PUFCOM	2
	REAL MATL, NEM, NET, NEMH, NETH	PUFCOM	3
C	MISCELLANEOUS	PUFCOM	4
	COMMON AZERO(1), CEF, CKS, DAVG, DELTIM, DISCPT(10), DOLD, DRHO, DTMAX,	PUFCOM	5
1	DTMIN, DTN, DTNH, DU, DX, EOLD, F, FAC, FIRST, J, JCYCS, JINIT,	PUFCOM	6
2	JFIN, JREZON(15), JSMAX, JSTAR, JTS, LSUB(30), M, MAXPR(30), N, NCYCS,	PUFCOM	7
3	NEDIT, NPERN, NR, NREZON, NSCRB(6), NSEPRAT, NSPALL, NTEDT,	PUFCOM	8
4	NTEX, NTR(15), POLD, P6(20), R(30), RLAST, SLAST, SMAX, TEDIT(50),	PUFCOM	9
5	TF, TIME, TJ, TREZON, TS, T6(20), ULAST, UOLD, UZERO, XLAST, XNOW, XOLD	PUFCOM	10
1	, XJDIT(20), MS	PUFCOM	11
C	HALFSTEP VALUES	PUFCOM	12
	COMMON DH, DHLAST, DUH, EH, PH, RH, RHLAST, SH, SHLAST, UH, UHLAST, XH, XHLAST	PUFCOM	13
1	, NEMH, NETH	PUFCOM	14
C	CONDITION INDICATORS	PUFCOM	15
	COMMON INF, LINTER, MIRROR, NORMAL, POROUS, PRESS, RINTER, SOLID, SPALL	PUFCOM	16
C	CELL LAYOUT	PUFCOM	17
	COMMON DXX(30), JBND(30), JMAT(30), NAUTO, MATL(6, 2), NLayer, NMTRLS,	PUFCOM	18
1	THK(30)	PUFCOM	19
C		PUFCOM	20
C	COORDINATE ARRAYS	COORDCOM	2
	COMMON/COORD/X(200), XO(200), CHL(200), DHL(200), DPDD(200), DPDE(200),	COORDCOM	3
1	EHL(200), H(200, 3), NEM(200), NET(200), PHL(200), RHL(200), SDT(200),	COORDCOM	4
2	SHL(200), T(200), U(200), YHL(200), ZHL(200)	COORDCOM	5
	COMMON /JED/JEDIT(100), JNUM(100), Jtyp(100), NAME2(40), JEDSIZ,	JEDCOM	2
1	MODLUS, NERR, NJEDIT, NTAPE	JEDCOM	3
C	NAMED COMMON	EQSTCOM	2
	REAL MU, MUM	EQSTCOM	3
	COMMON /EQS/ EQSTA(6), EQSTC(6), EQSTD(6), EQSTE(6), EQSTG(6),	EQSTCOM	4
1	EQSTH(6), EQSTN(6), EQSTS(6), EQSTV(6), CZQ(6), CWQ(6), C2(6)	EQSTCOM	5
	COMMON /MELT/ EMELT(6, 8), GMELT(6, 8), SPH(6), THERM(6, 8)	EQSTCOM	6
	COMMON /RHO/ RHO(6), RHOS(6)	EQSTCOM	7
	COMMON /TSR/ TSR(6, 30), EXMAT(6, 20), TENS(6, 3)	EQSTCOM	8
	COMMON /Y/ YO(6), YADD(6), MU(6), MUM, YADDM	EQSTCOM	9
	COMMON /IND/ IEOS(6), INDK(20), NALPHA, NCMP(6), NFR(6), NFOR(6),	INDCOM	2
1	NDS(6), NPR(6), NCON(6), NVAR(6)	INDCOM	3
	COMMON /RAD/ SSTOP(9), START(9), SDURM, SSTOPM, NSPEC, SSJ, JSS, Iplot(4)	RADCOM	2
1	, XMAX(4), XMIN(4), YMAX(4), YMIN(4), IA(7), ITITLE(24), NARZ, TARZ	RADCOM	3
	COMMON/SS/SS(500)	SSCOM	2
	COMMON/PES/COM(2000), LVAR(200), LVMAX	REZONE	19
C		REZONE	20
	DIMENSION CC(20), EC(20), HC(20, 3), MASS(21), MOM(20, 2), DC(20),	10/8/79	4
1	PC(20), RC(21), SC(20), XC(20), YC(20), ANEM(20), ANET(20)	REZONE	22
	DIMENSION NEWJED(100)	REZONE	23
	DIMENSION ASC(20), PSC(20), RSC(20), RVSC(20), ENSC(20)	REZONE	24
	DIMENSION SSS(5), SSC(20, 5)	REZONE	25
	INTEGER HC, HJOLD2	REZONE	26
C		REZONE	27
	REAL MASS, MOM, MASLAST, MOMLAST, MASNEXT	REZONE	28
C		REZONE	29
C		REZONE	30
1	CALL SECOND(XNOW)	REZONE	31
C		REZONE	32
C	SECTION 1 - LOCATE JREZON WITH RESPECT TO MATERIAL AND JEDITS	REZONE	33
C		REZONE	34
	JREZ=JREZON(NR)	REZONE	35
	DTD=0.	REZONE	36
3	IF (NREZON .GT. 0) GO TO 7	REZONE	37
	IF (JTS .GE. JFIN-2) RETURN	REZONE	38
	CALL EDIT	REZONE	39
	DTS=(X(JTS+1)-X(JTS))/CHL(JTS)	REZONE	40
	DTD=AMIN1(2.*DTS, 1.4*DTMAX)	REZONE	41
	JREZ=JTS	REZONE	42
	JBEG=1	REZONE	43
	DO 5 L=1, NLayer	REZONE	44
	JBNDM=JBND(L)-1	REZONE	45

SUBROUTINE REZONE (Continued)

	<pre> DO 4 JS=JBEG,JBNDM IF((X(JS+1)-X(JS))/CHL(JS) .GT. DTD) GO TO 4 JREZ=JS+1 4 CONTINUE JBEG=JBNDM+2 5 CONTINUE 7 JREZ=JLAST=MINO(JREZ,JFIN-1) IF (JREZ .LE. JINIT+1) RETURN L=0 8 L=L+1 IF (JREZ .GT. JBND(L)+1) GO TO 8 IF (JREZ .EQ. JBND(L)+1) JLAST=JLAST-1 MASLAST=ZHL(JLAST) MOMLAST=0.5*MASLAST*U(JLAST) TLAST=T(JLAST) C ** SET JOLD, THE OLD COORDINATE VALUE, AND JNEW, THE NEW VALUE C ** REZONING OCCURS FOR CELLS BETWEEN JOLD AND JLAST. MIDCELL C ** QUANTITIES ARE SET FOR JLAST-1 WHILE COORDINATE QUANTITIES ARE C ** SET FOR JLAST. C ** SET DX (CELL DIMENSION) AND XN (COORD TO LEFT OF NEW CELL) FOR C ** FIRST GROUP OF CELLS TO BE REZONED XN=X(JLAST-1) \$ DX=X(JLAST)-XN 11 L1=L-1 \$ DX(L)=DX=AMAX1(DX,DTD*CHL(JLAST-1)) DT=DX/CHL(JLAST-1) JOLD=JNEW=JLAST-1 \$ NCEL=NPART=0 IF (L .EQ. 1) GO TO 13 M=JMAT(L) DO 12 I=1,L1 MI=JMAT(I) 12 DX(I)=DX(L)*SQRT(EQSTC(MI)*RHOS(M)/(EQSTC(M)*RHOS(M))) 13 DO 10 I=1,NJEDIT 10 NEWJED(I)=JEDIT(I) LOC=11 WRITE (6,5011) JREZ,DT,DTNH WRITE (6,5000) LOC,JOLD,JNEW,JLAST,L,NJ,NCEL,NPART WRITE (6,5015) (I,DX(I),I=1,L) C C SECTION 2 - FIND REZONABLE SET OF CELLS C C TERMINATION OF REZONABLE SET OF CELLS AT AN INTERFACE (PART 1 50 IF (L-1) 790,155,52 52 IF (JOLD-JBND(L-1)-1) 790,60,155 60 NPART=1 \$ HJOLD2=H(JOLD,2) \$ GO TO 500 100 JLAST=JOLD-1 C ** RETURN WITH JNEW SET TO LEFT COORDINATE OF BOUNDARY, JOLD ON 125 H(JNEW+1,2)=HJOLD2 \$ X(JNEW)=X(JOLD-1) L=L-1 \$ JBND(L)=JNEW \$ TLAST=T(JOLD-1) \$ JNEW=JNEW-1 JOLD=JOLD-2 \$ XN=X(JOLD) LOC=125 WRITE (6,5000) LOC,JOLD,JNEW,JLAST,L,NJ,NCEL,NPART GO TO 50 C C TERMINATION AT INITIAL BOUNDARY (PART 2) 155 IF (JOLD-JINIT) 790,160,255 160 NPART=2 \$ HJOLD2=H(JOLD,2) \$ GO TO 500 200 H(JNEW+1,2)=HJOLD2 \$ DO 205 NJ=1,NJEDIT IF (JOLD .NE. JEDIT(NJ)) GO TO 205 NEWJED(NJ)=JNEW+1 GO TO 800 205 CONTINUE GO TO 800 C 255 CONTINUE 300 CONTINUE C C TERMINATION WHEN NUMBER OF REZONABLE OLD CELLS IS 20 (PART 355 IF ((X(JLAST)-X(JOLD))/DX(L)-18.) 420,360,360 360 NPART=4 \$ GO TO 500 400 JOLD=JOLD-1 LOC=400 C ** RETURN WITH JOLD AT PREVIOUS LOCATION, JNEW SET AT COORDINATE C ** LEFT. MIDCELL QUANTITIES HAVE BEEN RESET UP TO JNEW+1, COORDI C ** QUANTITIES UP TO JNEW+2 WRITE (6,5000) LOC,JOLD,JNEW,JLAST,L,NJ,NCEL,NPART GO TO 50 </pre>	<pre> REZONE 46 REZONE 47 REZONE 48 REZONE 49 REZONE 50 REZONE 51 REZONE 52 REZONE 53 REZONE 54 REZONE 55 REZONE 56 REZONE 57 REZONE 58 REZONE 59 REZONE 60 REZONE 61 REZONE 62 REZONE 63 REZONE 64 REZONE 65 REZONE 66 REZONE 67 REZONE 68 REZONE 69 REZONE 70 REZONE 71 REZONE 72 REZONE 73 REZONE 74 REZONE 75 REZONE 76 REZONE 77 REZONE 78 REZONE 79 REZONE 80 REZONE 81 REZONE 82 REZONE 83 REZONE 84 REZONE 5 REZONE 86 REZONE 87 REZONE 88 REZONE 89 REZONE 90 REZONE 91 REZONE 92 REZONE 93 REZONE 94 REZONE 95 REZONE 96 REZONE 97 REZONE 98 REZONE 99 REZONE 100 REZONE 101 REZONE 102 REZONE 103 REZONE 104 REZONE 105 REZONE 106 REZONE 107 REZONE 108 REZONE 109 REZONE 110 REZONE 111 REZONE 112 REZONE 113 REZONE 114 REZONE 115 REZONE 116 REZONE 117 REZONE 118 REZONE 119 REZONE 120 </pre>
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SUBROUTINE REZONE (Continued)

420	JOLD=JOLD-1 \$ GO TO 50	REZONE	121
C		REZONE	122
C	SECTION 3 - COMPUTE NEW CELL COORDINATES AND PROPERTIES	REZONE	123
C		REZONE	124
500	NQ=0	REZONE	125
	LCC=500	REZONE	126
	WRITE (6,5000) LCC,JOLD,JNEW,JLAST,L,NJ,NCEL,NPART	REZONE	127
510	NCEL=MIN0(20,MAX1((X(JLAST)-X(JOLD))/DXX(L)+.65,1.))	REZONE	128
	IF ((NCEL-1)*(NQ-1) .EQ. 0) GO TO 610	REZONE	129
C	CHECK WHETHER REGION OF LARGE CELLS LIES TO LEFT	REZONE	130
601	DXMIN=DXX(L) \$ JLASTP=JLAST-1	REZONE	131
	LCC=601	REZONE	132
	WRITE (6,5000) LCC,JOLD,JNEW,JLAST,L,NJ,NCEL,NPART	REZONE	133
	DO 603 JX=JOLD,JLASTP	REZONE	134
	DELX=X(JX+1)-X(JX)	REZONE	135
	IF (DELX-DXMIN) 602,603,603	REZONE	136
602	DXMIN=DELX \$ JXMIN=JX	REZONE	137
603	CONTINUE	REZONE	138
	IF (DXMIN-0.8*DXX(L)) 604,750,750	REZONE	139
604	JX=JXMIN+1	REZONE	140
	DO 605 I=JOLD,JXMIN	REZONE	141
	JX=JX-1 \$ DELX=X(JX+1)-X(JX)	REZONE	142
	IF (DELX-DXX(L)) 605,605,608	REZONE	143
605	CONTINUE \$ GO TO 610	REZONE	144
608	JOLD=JX+1 \$ NPART=4	REZONE	145
	LCC=608	REZONE	146
	WRITE (6,5000) LCC,JOLD,JNEW,JLAST,L,NJ,NCEL,NPART	REZONE	147
	NQ=1 \$ GO TO 510	REZONE	148
C		REZONE	149
C	BEGIN COMPUTATIONS FOR NEW COORDINATES	REZONE	150
610	NCEL=MIN0(JLAST-JOLD,NCEL)	REZONE	151
	JOLDR=JLAST	REZONE	152
	DX=(X(JLAST)-X(JOLD))/NCEL	REZONE	153
	XSTART=X(JLAST) \$ XN=XSTART-DX	REZONE	154
C	** XN IS NEW COORDINATE LOCATION	REZONE	155
C	** DX IS NEW CELL DIMENSION	REZONE	156
	MOM(1,1)=MOMLAST	REZONE	157
	MASS(1)=MASLAST	REZONE	158
	LCC=610	REZONE	159
	WRITE (6,5002) LCC,NCEL,XSTART,DX,XN,RSLAST,MASLAST,MOMLAST	REZONE	160
	WRITE (6,5610)	REZONE	161
	M=JMAT(L)	REZONE	162
	IF (NALPHA .GT. 1) XSTART=XSTART**NALPHA	10/8/79	6
	XNAOLD=XSTART	10/8/79	7
	DO 650 I=1,NCEL	REZONE	163
	MASS(I+1)=AMAVG=AMSLP=ENGY=CS=RS=PS=SX=YS=0. \$ ASUM=PSUM=RSUM=	REZONE	164
1	RVSUM=ENSUM=0.	REZONE	165
	XNAVALF=XN+DX/2.	10/8/79	8
	DXALF=DX	10/8/79	9
	IF (NALPHA .LE. 1) GO TO 611	10/8/79	10
	XNA=XN**NALPHA	10/8/79	11
	XNAVALF=0.5*(XNA+XNAOLD)	10/8/79	12
	DXALF=XNAOLD-XNA	10/8/79	13
	XNAOLD=XNA	10/8/79	14
611	CONTINUE	10/8/79	15
	DO 612 INS = 1,NSPEC	REZONE	166
612	SSS(INS) = 0.	REZONE	167
	HC(1,1)=SOLID	REZONE	168
	HC(1,2)=NORMAL	REZONE	169
	ANETS=ANETS=0.	REZONE	170
	HC(1,3)=2	REZONE	171
615	IF (JLAST .LT. 1) GO TO 625	REZONE	172
	XEND1=XEND=AMAX1(X(JLAST),XN)	10/8/79	16
	XJLALF1=X(JLAST+1)	10/8/79	17
	XJLALF=X(JLAST)	10/8/79	18
	IF (NALPHA .LE. 1) GO TO 616	10/8/79	19
	XEND=XEND**NALPHA	10/8/79	20
	XJLALF1=XJLALF1**NALPHA	10/8/79	21
	XJLALF=XJLALF**NALPHA	10/8/79	22
616	CONTINUE	10/8/79	23
	IF (XSTART-XEND) 621,621,619	REZONE	174
619	DMASS=ZHL(JLAST)*(XSTART-XEND)/(XJLALF1-XJLALF)	10/8/79	24
	MASS(I+1)=MASS(I+1)+DMASS	REZONE	176
	UJ=U(JLAST)	REZONE	177
	DUOLD=U(JLAST+1)-UJ	REZONE	178

SUBROUTINE REZONE (Continued)

	DXOLD=XJLALF1-XJLALF	10/8/79	25
	XS1=0.5*(XSTART+XEND)-XNAVALF	10/8/79	26
	XS2=XSTART-XEND	REZONE	181
	U1=UJ+DUOLD*(XEND-XJLALF)/DXOLD	10/8/79	27
	U2=UJ+DUOLD*(XSTART-XJLALF)/DXOLD	10/8/79	28
	AMAVG=0.25*DMASS*(U1+U2)+AMAVG	REZONE	184
	AMSLP=DMASS/DXALF*(1.5*(U2+U1)*XS1+0.25*(U2-U1)*XS2)+AMSLP	10/8/79	29
	ENGU=ENGU+DMASS*EHL(JLAST)	REZONE	186
	IF (TIME.GT. SSTOPM) GO TO 620	REZONE	187
	DO 6201 INS=1, NSPEC	REZONE	188
	JF=JFIN*(INS-1)+JLAST	REZONE	189
6201	SSS(INS)=SSS(INS)+DMASS*SS(JF)	REZONE	190
620	CONTINUE	REZONE	191
	RS=RS+DMASS*RHL(JLAST)	REZONE	192
	PS=PS+DMASS*PHL(JLAST)	REZONE	193
	SX=SX+DMASS*SHL(JLAST)	REZONE	194
	YS=YS+DMASS*YHL(JLAST)	REZONE	195
	CS=CS+DMASS*CHL(JLAST)	REZONE	196
	ANEMS=ANEMS+DMASS*NEM(JLAST)	REZONE	197
	ANETS=ANETS+DMASS*NET(JLAST)	REZONE	198
	LL=LVAR(JLAST)	REZONE	199
	IF (LL.EQ. 0) GO TO 6205	REZONE	200
	ASUM=ASUM+DMASS*COM(LL+2)	REZONE	201
	PSUM=PSUM+DMASS*COM(LL+1)	REZONE	202
	RSUM=RSUM+DMASS*COM(LL)	REZONE	203
	RVSUM=RVSUM+DMASS*COM(LL+3)	REZONE	204
	ENSUM=ENSUM+DMASS*COM(LL+4)	REZONE	205
6205	CONTINUE	REZONE	206
	HC(1,2)=MINO(HC(1,2),H(JLAST,2))	REZONE	207
	XSTART=XEND	REZONE	208
	IF ((H(JLAST,1).EQ. 5R P.OR. H(JLAST,1).EQ. 5R Q.OR. H	REZONE	209
	1 (JLAST,1).EQ. 5R T).AND. HC(1,1).EQ. SOLID)HC(1,1)=POROUS	REZONE	210
	IF (H(JLAST,1).EQ. 5R R.AND. HC(1,1).NE. 5R Z)HC(1,1)=5R	REZONE	211
	1 R	REZONE	212
	IF (H(JLAST,1).EQ. 5R Z)HC(1,1)=5R Z	REZONE	213
	HC(1,3)=MAXO(H(JLAST,3),HC(1,3))	REZONE	214
621	IF (XEND1.LE. XN) GO TO 625	10/8/79	30
	JLAST=JLAST-1 \$ GO TO 615	REZONE	216
625	XC(1)=XN \$ DC(1)=MASS(I+1)/DXALF \$ EC(1)=ENGU/MASS(I+1)	10/8/79	31
	YC(1)=YS/MASS(I+1) \$ SC(1)=SX/MASS(I+1) \$ PC(1)=PS/MASS(I+1)	REZONE	218
	CC(1)=CS/MASS(I+1) \$ RC(1)=RS/MASS(I+1)	REZONE	219
	ASC(1)=ASUM/MASS(I+1) \$ PSC(1)=PSUM/MASS(I+1)	REZONE	220
	RSC(1)=RSUM/MASS(I+1) \$ RVSC(1)=RVSUM/MASS(I+1)	REZONE	221
	ENSC(1)=ENSUM/MASS(I+1)	REZONE	222
	IF (TIME.GT. SSTOPM) GO TO 630	REZONE	223
	DO 628 INS=1, NSPEC	REZONE	224
628	SSC(1,INS)=SSS(INS)/MASS(I+1)	REZONE	225
630	CONTINUE	REZONE	226
	MOM(1,2)=AMAVG+AMSLP	REZONE	227
	MOM(1+1,1)=AMAVG-AMSLP	REZONE	228
	ANEM(1)=ANEMS/MASS(I+1) \$ ANET(1)=ANETS/MASS(I+1)	REZONE	229
643	K=JNEW+1-I	REZONE	230
	LDC=643	REZONE	231
	WRITE (6,5003) LDC,K,XC(1),DC(1),MOM(1,2),MOM(1+1,1),EC(1),RC(1),	10/8/79	32
	1 PC(1),SC(1),YC(1),MASS(I+1),HC(1,1)	REZONE	233
650	XN=AMAX1(XN-DX,X(JOLD))	REZONE	234
	T(JNEW+1)=TLAST	REZONE	235
	DO 6550 NJD=1,NJEDIT	REZONE	236
	IF (JEDIT(NJD).GT. JOLDR.OR. JEDIT(NJD).LT. JOLD) GO TO 6550	REZONE	237
	JED=JEDIT(NJD)	REZONE	238
	NEWJED(NJD)=JNEW+1-NCEL	REZONE	239
	XJED=0.5*(X(JED)+X(JED+1))	REZONE	240
	DO 6545 I=2,NCEL	REZONE	241
	IF (XJED.LT. 0.5*(XC(I)+XC(I-1))) GO TO 6545	REZONE	242
	NEWJED(NJD)=JNEW+2-I	REZONE	243
	GO TO 6550	REZONE	244
6545	CONTINUE	REZONE	245
6550	CONTINUE	REZONE	246
	DO 670 I=1,NCEL	REZONE	247
	J=JNEW+1-I \$ CHL(J)=CC(1) \$ DHL(J)=DC(1)	10/8/79	33
	EHL(J)=EC(1) \$ PHL(J)=PC(1) \$ SHL(J)=SC(1)	REZONE	249
	YHL(J)=YC(1) \$ ZHL(J)=MASS(I+1) \$ H(J,1)=HC(1,1)	REZONE	250
	NET(J)=ANET(1) \$ NEM(J)=ANEM(1) \$ RHL(J)=RC(1)	REZONE	251
	JL=JOLDR+1-I	REZONE	252
	LVAR(J)=LVAR(JL)	REZONE	253

SUBROUTINE REZONE (Continued)

LL=LVAR(J)	REZONE	254
IF (LVAR(J) .EQ. 0) GO TO 6555	REZONE	255
COM(LL)=RSC(I)	REZONE	256
COM(LL+1)=PSC(I)	REZONE	257
COM(LL+2)=ASC(I)	REZONE	258
COM(LL+3)=RVSC(I)	REZONE	259
COM(LL+4)=ENSC(I)	REZONE	260
6555 CONTINUE	REZONE	261
IF (TIME .GT. SSTOPM) GO TO 660	REZONE	262
DO 655 INS=1, NSPEC	REZONE	263
JF=JFIN*(INS-1)+J	REZONE	264
655 SS(JF)=SSC(I, INS)	REZONE	265
660 CONTINUE	REZONE	266
U(J+1)=2.*(MOM(I,1)+MOM(I,2))/(MASS(I)+MASS(I+1))	REZONE	267
T(J)=TENS(M,1) \$ X(J)=XC(I) \$ H(J,2)=HC(I,2)	REZONE	268
H(J,3)=HC(I,3)	REZONE	269
670 CONTINUE	REZONE	270
MOMLAST=MOM(NCEL+1,1)	REZONE	271
MASLAST=MASS(NCEL+1)	REZONE	272
TLAST=T(JOLD)	REZONE	273
GO TO (680,680,700,700,685) NPART	REZONE	274
680 CONTINUE	REZONE	275
685 T(J)=TLAST	REZONE	276
U(J)=2.*MOMLAST/MASLAST	REZONE	277
MOMLAST=MASLAST=RSLAST=0.	REZONE	278
700 CONTINUE	REZONE	279
LDC=700	REZONE	280
WRITE (6,5000) LDC, JOLD, JNEW, JLAST, L, NJ, NCEL, NPART	REZONE	281
C SET JNEW AND JLAST IN PREPARATION FOR THE NEXT ZONE CALCULATIONS	REZONE	282
JNEW=J-1 \$ JLAST=JOLD	REZONE	283
C RETURN TO APPROPRIATE PART OF REZONE FOR FINAL RESETTNG	REZONE	284
GO TO (100,200,300,400) NPART	REZONE	285
C	REZONE	286
C RENUMBER CELLS WITHOUT REZONING	REZONE	287
750 T(JNEW+1)=TLAST	REZONE	288
LDC=750	REZONE	289
TLAST=T(JOLD)	REZONE	290
WRITE (6,5750)	REZONE	291
752 JLAST=JLAST-1 \$ DHL(JNEW)=DHL(JLAST)	REZONE	292
EHL(JNEW)=EHL(JLAST) \$ PHL(JNEW)=PHL(JLAST)	REZONE	293
IF (TIME .GT. SSTOPM) GO TO 754	REZONE	294
DO 753 INS=1, NSPEC	REZONE	295
JF=JFIN*(INS-1)	REZONE	296
753 SS(JF+JNEW)=SS(JF+JLAST)	REZONE	297
754 CONTINUE	REZONE	298
SHL(JNEW)=SHL(JLAST) \$ YHL(JNEW)=YHL(JLAST)	REZONE	299
CHL(JNEW)=CHL(JLAST) \$ ZHL(JNEW)=ZHL(JLAST)	REZONE	300
H(JNEW,1)=H(JLAST,1) \$ H(JNEW,2)=H(JLAST,2)	REZONE	301
MASNEXT=ZHL(JLAST) \$ RHL(JNEW)=RHL(JLAST)	REZONE	302
U(JNEW+1)=(2.*MOMLAST+MASNEXT*U(JLAST+1))/(MASLAST+MASNEXT)	REZONE	303
MASLAST=MASNEXT	REZONE	304
MOMLAST=.5*MASLAST*U(JLAST)	REZONE	305
T(JNEW)=T(JLAST) \$ X(JNEW)=X(JLAST)	REZONE	306
NEM(JNEW)=NEM(JLAST) \$ NET(JNEW)=NET(JLAST)	REZONE	307
H(JNEW,3)=H(JLAST,3)	REZONE	308
LVAR(JNEW)=LVAR(JLAST)	REZONE	309
DO 7550 NJD=1, NJEDIT	REZONE	310
IF (JEDIT(NJD) .EQ. JLAST) NEWJED(NJD)=JNEW	REZONE	311
7550 CONTINUE	REZONE	312
I=JNEW \$ JNEW=JNEW-1	REZONE	313
WRITE (6,5003) LDC, I, X(I), DHL(I), U(I+1), EHL(I), RHL(I), PHL(I),	REZONE	314
1 SHL(I), YHL(I), T(I), ZHL(I), H(I,1)	REZONE	315
IF (JLAST-JOLD) 790,755,752	REZONE	316
C ** JNEW IS TO LEFT OF LAST RENUMBERED CELL. JLAST=JOLD, THE LAST	REZONE	317
C ** OLD COORDINATE RENUMBERED.	REZONE	318
755 CONTINUE	REZONE	319
LDC=755	REZONE	320
WRITE (6,5000) LDC, JOLD, JNEW, JLAST, L, NJ, NCEL, NPART	REZONE	321
GO TO (760,760,300,400,765) NPART	REZONE	322
760 CONTINUE	REZONE	323
765 U(JNEW+1)=2.*MOMLAST/MASLAST	REZONE	324
T(JNEW+1)=T(JLAST)	REZONE	325
MOMLAST=MASLAST=RSLAST=0.	REZONE	326
LDC=760	REZONE	327
WRITE (6,5000) LDC, JOLD, JNEW, JLAST, L, NJ, NCEL, NPART	REZONE	328

SUBROUTINE REZONE (Concluded)

GO TO (100,200,300,400) NPART	REZONE	329
C	REZONE	330
C	REZONE	331
C	REZONE	332
790 WRITE (6,1000) NPART,JOLD,JNEW,JLAST,NJ,JEDIT(NJ),L,JBND(L)	REZONE	333
CALL EDIT \$ LSUB(M)=1 \$ CALL STORR \$ CALL SCRIBE \$ STOP	REZONE	334
C	REZONE	335
C	REZONE	336
C	REZONE	337
800 JINIT=JNEW+1	REZONE	338
IF (H(JINIT,2) .EQ. SPALL) R(1)=0.	REZONE	339
DO 820 L=1,NLAYER	REZONE	340
JB=JBND(L) \$ H(JB,2)=LINTER	REZONE	341
IF (H(JB+1,2) .EQ. SPALL) GO TO 820	REZONE	342
U(JB+1)=U(JB)=(U(JB)*ZHL(JB-1)+U(JB+1)*ZHL(JB+1))/(ZHL(JB-1)+	REZONE	343
1 ZHL(JB+1))	REZONE	344
820 CONTINUE	REZONE	345
WRITE (6,5825)	REZONE	346
WRITE (6,5826) (JEDIT(NJ),NJ=1,NJEDIT)	REZONE	347
WRITE (6,5827) (NEWJED(NJ),NJ=1,NJEDIT)	REZONE	348
DO 825 I=1,NJEDIT	REZONE	349
JEDIT(I)=NEWJED(I)	REZONE	350
840 CALL EDIT	REZONE	351
900 CONTINUE	REZONE	352
CALL SECOND(TWIX) \$ DUR=TWIX-XNOW	REZONE	353
WRITE (6,5010) JINIT,DUR	REZONE	354
RETURN	REZONE	355
1000 FORMAT (24H ERROR IN REZONE, NPART=13,6H JOLD=13,6H JNEW=13,	REZONE	356
1 7H JLAST=13,4H NJ=13,11H JEDIT(NJ)=13,3H L=13,9H JBND(L)=13)	REZONE	357
5000 FORMAT (13H REZONE, LOC=13,7H, JOLD=13,7H, JNEW=13,8H, JLAST=13,	REZONE	358
1 4H, L=13,5H, NJ=13,7H, NCEL=13,8H, NPART=13)	REZONE	359
5002 FORMAT(13H REZONE, LOC=13,7H, NCEL=13,15H, XSTART,DX,XN=1P3E10.3,	REZONE	360
1 9H, RSLAST=1PE10.3,10H, MASLAST=1PE10.3,10H, MOMLAST=1PE10.3)	REZONE	361
5003 FORMAT(215,1P10E10.3,3X,R1)	REZONE	362
5010 FORMAT(19HOEND REZONE, JINIT=13,17H, TIME IN REZONE=1PE10.3,5H SEC	REZONE	363
1)	REZONE	364
5011 FORMAT (//5X,*BEGINNING OF REZONING, JREZ=*13,*, INTENDED DT=*	REZONE	365
1 1PE10.3,*, DTNH=*1PE10.3)	REZONE	366
5015 FORMAT(21H REZONE, DX VALUES ,6(18,F9.6)/21X,6(18,F9.6))	REZONE	367
5610 FORMAT (120H LOC J PC XC DC MOM(1,2) MOM(1+1,1)	REZONE	368
1 EC RC PC SC YC MASS(1+1) HC(1,1)	REZONE	369
2)	REZONE	370
5750 FORMAT (120H LOC J X YHL DHL U(1+1) EHL	REZONE	371
1 RHL PHL SHL YHL T ZHL H(1,1)	REZONE	372
2)	REZONE	373
5825 FORMAT (* TRANSFORMATION OF JEDIT VALUES*)	REZONE	374
5826 FORMAT (* OLD JEDITS = *1815)	REZONE	375
5827 FORMAT (* NEW JEDITS = *1815)	REZONE	376
END	REZONE	377

SUBROUTINE SCATTO

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SUBROUTINE SCATTO (XS,ES,ECAL,NPDINT,NS,L,ESUM)
C
C      CALLED BY OEPDS TO DISTRIBUTE ABSORBED ENERGY INTO PUFF CELLS.
C      THE ENERGY HAS BEEN PREVIOUSLY COMPUTED BY A FLUORESCENCE AND
C      SCATTERING CODE (SUCH AS FSCATT OF S.S.S.) OR DETERMINED
C      EXPERIMENTALLY. DEPOSITION COORDINATES MAY BE SPACED ARBI-
C      TRARILY. INTERPOLATION FUNCTION IS A PARABOLA IN LOG(E) VS X
C      FITTED THROUGH 3 DEPOSITION COORDINATES.
C      INPUT - FORMAL PARAMETERS WHICH CONTAIN COORDINATES (XS) AT WHICH
C      DOSE (ES) IS KNOWN, NPOINT (NUMBER OF COORDINATE POINTS, ECAL
C      (CALIBRATION FACTOR), AND NS (SPECTRUM NUMBER). ES SHOULD
C      BE IN CAL/CM2, XS IN CM.
C      OUTPUT - FILLS SS ARRAY.
C
C      INTEGER H,PORDUS,PRESS,RINTER,SDLIO,SPALL
C      REAL MATL,NEM,NET,NEMH,NETH
C      MISCELLANEOUS
C      COMMOND AZERO(1),CEF,CKS,DAVG,DELTIM,OISCPT(10),DDLD,DRHO,DTMAX,
1  DTMIN,OTN,DTNH,OU,DX,EOLD,F,FAC,FIRST,J,JCYCS,JINIT,
2  JFIN,JREZDN(15),JSMAX,JSTAR,JTS,LSUB(30),M,MAXPR(30),N,NCYCS,
3  NEDIT,NPERN,NR,NREZON,NSCRB(6),NSEPRAT,NSPALL,NTEDT,
4  NTEX,NTR(15),PDLD,P6(20),R(30),RLAST,SLAST,SMAX,TEDIT(50),
5  TF,TIME,TJ,TREZON,TS,T6(20),ULAST,UOLD,UZERD,XLAST,XNOW,XOLD
1  ,XJDDIT(20)
C      HALFSTEP VALUES
C      COMMOND DH,DHLAST,OUH,EH,PH,RH,RHLAST,SH,SHLAST,UH,UHLAST,XH,XHLAST
1  ,NEMH,NETH
C      CONDITION INDICATORS
C      COMMOND INF,LINTER,MIRDR,NDRMAL,POROUS,PRESS,RINTER,SOLID,SPALL
C      CELL LAYOUT
C      COMMOND OXX(30),JBNO(30),JMAT(30),NAUTD,MATL(6,2),NLAYER,NMTRLS,
1  THK(30)
C      COORDINATE ARRAYS
C      COMMOND/CDDRD/X(200),X0(200),CHL(200),DHL(200),OPDD(200),OPOE(200),
1  EHL(200),H(200,3),NEM(200),NET(200),PHL(200),RHL(200),SDT(200),
2  SHL(200),T(200),U(200),YHL(200),ZHL(200)
C      NAMED COMMON
C      REAL MU,MUM
C      COMMOND /EQS/ EQSTA(6),EQSTC(6),EQSTD(6),EQSTE(6),EQSTG(6),
1  EQSTH(6),EQSTN(6),EQSTS(6),EQSTV(6),CZQ(6),CWQ(6),C2(6)
C      COMMON /MELT/ EMELT(6,5),SPH(6),THERM(6,8)
C      COMMON /RHO/ RHO(6),RHDS(6)
C      COMMOND /TSR/ TSR(6,30),EXMAT(6,20),TENS(6,3)
C      COMMOND /Y/ Y0(6),YADD(6),MU(6),MUM,YADDM
C      COMMON /RAD/ SSTOP(5),START(5),SDURM,SSTOPM,NSPEC,SSJ,JSS,IPL0T(4)
1  ,XMAX(4),XMIN(4),YMAX(4),YMIN(4),IA(7),ITITLE(24),NARZ,TARZ
C      COMMON/SS/SS(500)
C
C      DIMENSIOND XS(1),ES(1)
C
C      FACTDR=4.186E7/(SSTOP(NS)-START(NS))
C      ESS=ESUM=0.
C      JFINNS=JFIN*(NS-1)
C      JS1=J=1
C      BEGIN LDDP FOR EACH MATERIAL
C      IF (L.GT. 1) J=JBNO(L-1)+1
C      XENO=X(J)
C      JBNDM=JBND(L)
C      XTH=X(JBNOM)
492 JS2=JS1+1 $ JS3=JS1+2
C      XSTD=0.5*(XS(JS2)+XS(JS3))
C      IF (JS3.EQ. NPDINT) XSTD=XTH
C      SET UP FOR INTEGRATION BY SIMPSONS RULE. SEMILDG PARABOLA IN
C      LOG(E)=Z1*LOG(E1)+Z2*LOG(E2)+Z3*LOG(E3)
C      WHERE Z(J)=-R(I,J)*R(J,K) AND R(I,J)=(X-X(K))/(X(J)-X(I))
C      ES1=ALOG(AMAX1(ES(JS1),1.E-10))

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SUBROUTINE SCATTO (Concluded)

	ES2=ALOG(AMAX1(ES(JS2),1.E-10))	SCATT041
	ES3=ALOG(AMAX1(ES(JS3),1.E-10))	SCATT042
	X1=XS(JS1) \$ X2=XS(JS2) \$ DX12=X2-X1 \$ X3=XS(JS3)	SCATT043
	DX13=X3-X1 \$ DX23=X3-X2	SCATT044
494	R12=(XEND-X3)/DX12 \$ R23=(XEND-X1)/DX23 \$ R31=-(XEND-X2)/DX13	SCATT045
	ESS1=EXP(-ES1*R12*R31-ES2*R23*R12-ES3*R31*R23)	SCATT046
495	XBEG=XEND	SCATT047
	XEND=AMIN1(XSTOP,X(J+1))	SCATT048
	R12=(XEND-X3)/DX12 \$ R23=(XEND-X1)/DX23 \$ R31=-(XEND-X2)/DX13	SCATT049
	ESS3=EXP(-ES1*R12*R31-ES2*R23*R12-ES3*R31*R23)	SCATT050
	XM=(XBEG+XEND)/2.	SCATT051
	R12=(XM -X3)/DX12 \$ R23=(XM -X1)/DX23 \$ R31=-(XM -X2)/DX13	SCATT052
	ESS2=EXP(-ES1*R12*R31-ES2*R23*R12-ES3*R31*R23)	SCATT053
	ESS=(XEND-XBEG)/6.*(ESS1+4.*ESS2+ESS3) + ESS	SCATT054
	ESS1=ESS3	SCATT055
	IF (ABS(XEND-X(J+1)) .LT. 1.E-10) GO TO 496	SCATT056
C	PREPARE FOR NEW SET OF THREE XS COORDINATE POINTS	SCATT057
	IF (JS3 .LT. NPOINT) JS1=JS1+1	SCATT058
	GO TO 492	SCATT059
496	DX=X(J+1)-X(J)	SCATT060
	SS(JFINNS+J)=ESS*FACTOR/DX	SCATT061
	ESUM=ESUM+ESS	SCATT062
C	PREPARE FOR NEXT PUFF CELL	SCATT063
	IF (XEND.GT. XS(NPOINT) .AND. ES(NPOINT) .LE. .01) GOTO 500	SCATT064
	ESS=0.	SCATT065
	J=J+1	SCATT066
	IF (XEND .LT. XTH-1.E-10) GO TO 495	SCATT067
500	M = JMAT(L)	SCATT068
	RETURN	SCATT069
	END	SCATT070

SUBROUTINE SCRIBE

	SUBROUTINE SCRIBE	SCRIBE 2
	INTEGER H,POROUS,PRESS,RINTER,SOLIO,SPALL	PUFCOM 2
	REAL MATL,NEM,NET,NEMH,NETH	PUFCOM 3
C	MISCELLANEOUS	PUFCOM 4
	COMMON AZERO(1),CEF,CKS,OAVG,OELTIM,OISCPT(10),DOLO,DRHO,DTMAX,	PUFCOM 5
1	OTMIN,DTN,OTNH,DU,DX,EOL0,F,FAC,FIRST,J,JCYCS,JINIT,	PUFCOM 6
2	JFIN,JREZON(15),JSMAX,JSTAR,JTS,LSUB(30),M,MAXPR(30),N,NCYCS,	PUFCOM 7
3	NEDIT,NPERN,NR,NREZON,NSCRB(6),NSEPRAT,NSPALL,NTEDT,	PUFCOM 8
4	NTEX,NTR(15),POLO,P6(20),R(30),RLAST,SLAST,SMAX,TEOIT(50),	PUFCOM 9
5	TF,TIME,TJ,TREZON,TS,T6(20),ULAST,UOLO,UZERO,XLAST,XNOW,XOLO	PUFCOM10
1	,XJOIT(20)	PUFCOM11
C	HALFSTEP VALUES	PUFCOM12
	COMMON DH,OHLAST,OUH,EH,PH,RH,RHLAST,SH,SHLAST,UH,UHLAST,XH,XHLAST	PUFCOM13
1	,NEMH,NETH	PUFCOM14
C	CONDITION INOICATORS	PUFCOM15
	COMMON INF,LINTER,MIRROR,NORMAL,POROUS,PRESS,RINTER,SOLIO,SPALL	PUFCOM16
C	CELL LAYOUT	PUFCOM17
	COMMON DXX(30),JBND(30),JMAT(30),NAUTO,MATL(6,2),NLAYER,NMTRLs,	PUFCOM18
1	THK(30)	PUFCOM19
C		PUFCOM20
C	COORDINATE ARRAYS	COORDC02
	COMMON/COORD/X(200),X0(200),CHL(200),OHL(200),DPOO(200),OPOE(200),	COORDC03
1	EHL(200),H(200,3),NEM(200),NET(200),PHL(200),RHL(200),SOT(200),	COORDC04
2	SHL(200),T(200),U(200),YHL(200),ZHL(200)	COORDC05
	COMMON/NSC/A(5000)	NSCCOM 2
	COMMON /JEO/JEOIT(100),JNUM(100),JTYP(100),NAME2(40),JEDSIZ,	JEDCOM 2
1	MOOLUS,NERR,NJEOIT,NTAPE	JEOCOM 3
	DIMENSION JV(13)	SCRIBE 7
	NTAPE=3	SCRIBE 8
	REWIND 7	SCRIBE 9
	WRITE (7) N	SCRIBE10
	CALL SECONO(XSTART)	SCRIBE11
	IF (NERR .GT. 0) PRINT 1083,NERR	SCRIBE12
	NSC=(NJEDIT+2)/10+1	SCRIBE13
	NBUF=(N-1)/MOOLUS+1	SCRIBE14
	NPERP=50/MOOLUS	SCRIBE15
C		SCRIBE16
C	BEGIN OO LOOP OVER EACH SCRIBE LISTING	SCRIBE17
C		SCRIBE18
	DO 900 NS=1,NSC	SCRIBE19
	LENGTH=MOOLUS	SCRIBE20
	IPAG=1	SCRIBE21
	IF (UNIT(NTAPE)) 650,990,640	SCRIBE22
640	PRINT 1082	SCRIBE23
	REWIND NTAPE	SCRIBE24
C		SCRIBE25
C	BUFFER IN FIRST RECORD OF TAPE	SCRIBE26
650	BUFFER IN (NTAPE,1) (A1,A1)	SCRIBE27
	IF (UNIT(NTAPE)) 655,990,652	SCRIBE28
652	PRINT 1082	SCRIBE29
655	BUFFER IN (NTAPE,1) (A(1),A(JEDSIZ*MOOLUS))	SCRIBE30
	IF (NS .GT. 1) GO TO 680	SCRIBE31
	JENO=MINO(12,NJEOIT+5)	SCRIBE32
	JBEG=3	SCRIBE33
	JV(1)=10H(0PF6.0,	SCRIBE34
	JV(2)=10HF10.3	SCRIBE35
	JV(3)=10H,F10.3	SCRIBE36
	JV(4)=10H,F10.3	SCRIBE37
	JV(5)=10H,F6.0	SCRIBE38
	JV(13)=10H)	SCRIBE39
	OO 670 I=1,7	SCRIBE40
	JJ=I+5	SCRIBE41
	JV(JJ)=10H,1PE11.3	SCRIBE42
	IF (JNUM(I) .GE. 1400 .AND. JNUM(I) .LT. 2000) JV(JJ)=9H,10X,A1	SCRIBE43
	IF (I .GT. NJEOIT) JV(JJ)=1H	SCRIBE44
670	CONTINUE	SCRIBE45
	GO TO 695	SCRIBE46
680	JBEG=JENO+1	SCRIBE47

SUBROUTINE SCRIBE (Concluded)

JEND=MIN0(JBEG+9,NJEDIT+5)	SCRIBE48
JD=JBEG+9	SCRIBE49
DO 690 I=JBEG,JD	SCRIBE50
JJ=I-JBEG+3	SCRIBE51
JE=I-5	SCRIBE52
JV(JJ)=I0H,IPE11.3	SCRIBE53
IF (JNUM(JE) .GE. I400 .AND. JNUM(JE) .LT. 2000)	SCRIBE54
1 JV(JJ)=9H,I0X,A1	SCRIBE55
IF (I .GT. NJEDIT+5) JV(JJ)=1H	SCRIBE56
690 CONTINUE	SCRIBE57
695 DO 850 NB=1,NBUF	SCRIBE58
IF (UNIT(NTAPE)) 710,990,700	SCRIBE59
700 PRINT 1082	SCRIBE60
710 IF (NB .NE. NBUF) GO TO 750	SCRIBE61
IF (MOD(N,MODLUS) .EQ. 0) GO TO 770	SCRIBE62
LENGTH=MOD(N,MODLUS)	SCRIBE63
GO TO 770	SCRIBE64
C BUFFER IN RECORDS	SCRIBE65
750 JBUF=MOD(NB,2)*2500	SCRIBE66
BUFFER IN (NTAPE,1)(A(JBUF+1),A(JBUF+2500))	SCRIBE67
770 CONTINUE	SCRIBE68
J1=MOD(NB-1,2)*2500	SCRIBE69
J2=(LENGTH-1)*JEDSIZ+J1	SCRIBE70
JB=JBEG-5	SCRIBE71
JD=JEND-5	SCRIBE72
IF (IPAG .EQ. I .AND. NS .GT. 1) PRINT 1200,DISCPT,NS,(JTYP(I),	SCRIBE73
1 I=JB,JD)	SCRIBE74
IF (IPAG .EQ. I .AND. NS .EQ. 1) PRINT 1100,DISCPT,NS,(JTYP(I),	SCRIBE75
1 I=1,JD)	SCRIBE76
PRINT JV,((A(I+J),I=1,2),(A(I+J),I=JBEG,JEND),J=J1,J2,JEDSIZ)	SCRIBE77
IPAG=MOD(IPAG,NPERP)+1	SCRIBE78
850 CONTINUE	SCRIBE79
REWIND NTAPE	SCRIBE80
900 CONTINUE	SCRIBE81
CALL SECOND(XEND)	SCRIBE82
DUR=XEND-XSTART	SCRIBE83
DUR2=XEND-FIRST	SCRIBE84
PRINT 1900,DUR,DUR2	SCRIBE85
RETURN	SCRIBE86
990 PRINT 1084	SCRIBE87
RETURN	SCRIBE88
1082 FORMAT (32H PARITY ERROR ON NTAPE IN SCRIBE)	SCRIBE89
1083 FORMAT (* EOFs AND PARITY ERRORS ON TAPE 3, NERR =*I3)	SCRIBE90
1084 FORMAT (29H EOF FOUND ON NTAPE IN SCRIBE)	SCRIBE91
1100 FORMAT (1H1,10A10/* SCRIBE NO. *I2,* USUAL UNITS ARE DYN, CM, SEC,	SCRIBE92
1 GRAM, EXCEPT TIME IN MICROSEC, DTNH IN NANOSEC*/	SCRIBE93
2 5X,*N*,6X,*TIME*,6X,*DTNH*,4X,*DELTIM*,3X,*JTS*,7(1X,A10))	SCRIBE94
1200 FORMAT (1H1,10A10/* SCRIBE NO. *I2,* USUAL UNITS ARE DYN, CM, SEC,	SCRIBE95
2 GRAM*/ 5X,*N*,6X,*TIME*,10(1X,A10))	SCRIBE96
1900 FORMAT (17H0TIME IN SCRIBE = F10.3/17H COMPUTING TIME = F10.3)	SCRIBE97
END	SCRIBE98

SUBROUTINE SHEAR2

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SHEAR2 1 SHEAR2 2 SHEAR2 3 SHEAR2 4 SHEAR2 5 SHEAR2 6 SHEAR2 7 SHEAR2 8 SHEAR2 9 SHEAR210 SHEAR211 SHEAR212 SHEAR213 SHEAR214 SHEAR215 SHEAR216 SHEAR217 SHEAR218 SHEAR219 SHEAR220 SHEAR221 SHEAR222 SHEAR223 SHEAR224 SHEAR225 SHEAR226 SHEAR227 SHEAR228 SHEAR229 SHEAR230 SHEAR231 SHEAR232 SHEAR233 SHEAR234 SHEAR235 SHEAR236 SHEAR237 SHEAR238 SHEAR239 SHEAR240 SHEAR241 SHEAR242 SHEAR243 SHEAR244 SHEAR245 SHEAR246 SHEAR247 SHEAR248 SHEAR249 SHEAR250 SHEAR251 SHEAR252 SHEAR253 SHEAR254 SHEAR255 SHEAR256 SHEAR257 SHEAR258 SHEAR259 SHEAR260 SHEAR261 SHEAR262 SHEAR263 SHEAR264 SHEAR265 SHEAR266 SHEAR267 SHEAR268 SHEAR269
SUBROUTINE SHEAR2(CALL,IN,M,K,J,IH3, SX,SY,SZ, SXY,P,TAU,DH,DOLD,
1DT0,EH,EOLD,EN,FMELT,EP,EX,EY,EZ,EXY,F,YHL,PLEN,ROT,OROT,ESC,CN)
ROUTINE FOR COMPUTATION OF STRESSES WITH RATE-DEPENDENT
YIELD MODEL FOR DEVIATORS AND MIE-GRUNEISEN FOR PRESSURE.
IF THRESHOLD PLASTIC STRAIN IS REACHED, SHEAR BANDS ARE
NUCLEATED AND GROWN IN 6 ORIENTATIONS.
SX, SY, SZ ARE DEVIATORS IN EXTERNAL SIGN CONVENTION.
P IS POSITIVE IN COMPRESSION. INTERNAL SIGN CONVENTION IS
POSITIVE IN COMPRESSION FOR ALL STRESS AND STRAIN QUANTITIES
ST IS TOTAL STRESS AT PREVIOUS TIME. SE IS NEW DEVIATOR.
EX, EY, EZ, EXY ARE STRAIN INCREMENTS IN EXTERNAL SIGN CON.
SS, SSE CHANGE EXTERNAL SIGN CONVENTION TO INTERNAL FOR
STRESS AND STRAIN, RESPECTIVELY.
DIMENSION BFR(6,35),NSIZE(30,9),FNUC(9),TAUZ(6),EFR(3),VFR(6),
1ST(4),ES(4),SE(4),TEP(6),ESC(6,20),NSIZT(6)
2 ,CN(100),DEP(4),CLA(100),CNA(100),VMAX(6)
EQUIVALENCE (CNA,CLA)
STRESS IS NEG IN TENSION
DATA SS,SSE/-1.,-1./
NC1=NCALL+1
GO TO (10,10,100,100,900)NC1
READ(1N,1002) A1,A2,(BFR(M,I),I=22,35)
PRINT 1002, A1,A2,(BFR(M,I),I=22,35)
FORMAT(2A5,7E10.3/10X,7E10.3)
READ(1N,1003)A1,A2,(NSIZE(M,I),I=1,9)
PRINT 1003,A1,A2,(NSIZE(M,I),I=1,9)
FORMAT(2A5,14I5)
VMAX(M)=0.
NSIZT(M)=NSIZE(M,1)
DO 14 I=2,9
NSIZT(M)=NSIZT(M)+NSIZE(M,I)
VFR(M)=1.
IF (NCALL.EQ. 1) GO TO 65
NANG=BFR(M,32)
KLAST=0
DO 16 I=1,3
FNUC(I)=.111111
FNUC(I+3)=.222222
IF(NANG = 6) 20,40,30
FNUCI=.333333
IF (NANG .GE. 4) FNUCI =.25
DO 25 I=1,4
FNUC(I)=FNUCI
IF (NANG .EQ. 2) FNUC(2) =.6666667
IF (NANG .NE. 5) GO TO 30
FNUC(4)=.125
FNUC(7)=.125
FNUC(5)=0.
FNUC(6)=0.
GO TO 40
DO 35 I=7,NANG
FNUC(I)=.111111
FNUC(I-3)=.111111
CONTINUE
RETURN
*****
COMPUTE STRESS AND DAMAGE
*****
IF (IH3 .GE. 25) GO TO 800
IF (VMAX(M) .EQ. 0.) VMAX(M)=SQRT(ESC(M,5)/ESC(M,1))
COMPUTE STRESS REDUCTION FACTORS TAUZ(1)
TAU=0.
JN=0
DO 110 NG=1,NANG

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SUBROUTINE SHEAR2 (Continued)

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      TAUZ(NG)=0.
      IF(NSIZE(M,NG) .EQ. 0 .OR. CN(JN+1) .EQ. 0.)GO TO 110
      NSIZE=NSIZE(M,NG)
      DO 120 I=1,NSIZE
      JNN=JN+2*I-1
120   TAUZ(NG)=TAUZ(NG)+CN(JNN)*CN(JNN+1)**3
      TAU=TAU+TAUZ(NG)
110   JN=JN+2*NSIZE(M,NG)
C*****
C      INITIAL TRANSFORMATION
C*****
C      ADJUST SIGNS,ROTATE STRESS,TRANSFORM TO STRESS IN SOLID(ST)
      RT=ROT+ROT+DROT
      EMU=DOLD/ESC(M,1)-1.
      PH=EMU*(ESC(M,2)+EMU*(ESC(M,3)+EMU*ESC(M,4)))
      PS=PH*(1.-ESC(M,9)*EMU/2.)+DOLD*ESC(M,9)*EOLD
      IF(PS .GT. 0.) P=P-PS*TAU
      SA=(SX+SY)*SS/2.+P
      SOR=SIN(RT)
      COR=COS(RT)
      SB=((SX-SY)/2.*COR+SXY*SOR)*SS
      DO 140 I=1,4
140   ST(I)=0.
      G2=2.*ESC(M,5)
      ST(1)=(SA+SB)/AMAX1(0.02,(1.-(3.*TAUZ(1)+1.5*(TAUZ(4)+TAUZ(5)))
1 *VFR(M)))
      ST(2)=(SA-SB)/AMAX1(0.02,(1.-(3.*TAUZ(2)+1.5*(TAUZ(4)+TAUZ(6)))
1 *VFR(M)))
      ST(3)=(P-(SX+SY)*SS)/AMAX1(0.02,(1.-(3.*TAUZ(3)+1.5*(TAUZ(5)+
1 TAUZ(6)))*VFR(M)))
      ST(4)=((SY-SX)/2.*SOR+SXY*COR)*SS/(1.-(1.5*(TAUZ(1)+TAUZ(2))+3.
1 *TAUZ(4))*VFR(M))
      IF(J.EQ. 17 .AND. TAU .GT. 0.05) PRINT 1400,SX,SY,SZ,P,ST,EX,EY,DHS
1400  FORMAT(10H SX,SY,SZ=3E10.3,3H P=E10.3,4H ST=4E10.3/7H EX,EY=2E10.3
1 ,4H DH=F10.5)
      P=(ST(1)+ST(2)+ST(3))/3.
C      ROTATE STRAINS TO BAND ORIENTATIONS
      EA=(EX+EY)/2.
      EB=(EX-EY)/2.*COR+EXY*SOR
      EBAR=0.6667*(DH-DOLD)/(DH+DOLD)
      NSTEP=SQRT((ABS(EA)+ABS(EB)+ABS(EBAR))/0.002)
      NSTEP=MAX0(NSTEP,1)
      ES(1)=(EA+EB)*SSE/NSTEP
      ES(2)=(EA-EB)*SSE/NSTEP
      ES(3)=3.*EBAR/NSTEP-ES(1)-ES(2)
      ES(4)=(((EY-EX)/2.*SOR+EXY*COR)*SSE)/NSTEP
      DO 600 NS=1,NSTEP
      DO 160 I=1,3
160   SE(I)=ST(I)+G2*(ES(I)-EBAR/NSTEP)-P
      SE(4)= ST(4)+G2*ES(4)
      SN=SQRT(1.5*(SE(1)**2+SE(2)**2+SE(3)**2+.5*SE(4)**2))
      DHN=DOLD+FLOAT(NS)/FLOAT(NSTEP)*(DH-DOLD)
      EMU=DHN/ESC(M,1)-1.
      PH=EMU*(ESC(M,2)+EMU*(ESC(M,3)+EMU*ESC(M,4)))
      PE=PH*(1.-ESC(M,9)*EMU/2.)+DHN*ESC(M,9)*EH
      Y1=AMAX1(0.,YHL+BFR(M,33)*PE)
      IF (SN .LT. Y1) GO TO 500
C*****
C      YIELD AND PLASTIC STRAIN CALCULATIONS
C*****
      EXPT = EXP(-DIO/BFR(M,30)/NSTEP)
      YEG=(Y1+BFR(M,31)*SN/2./G2)/(1.+BFR(M,31)/2./G2)/SN
      DO 180 I=1,3
180   SE(I)=(ST(I)-P)*EXPT+(YEG*SE(I)+BFR(M,30)*(SE(I)-ST(I)+P)/
1 DIO*NSTEP)*(1.-EXPT)
      SE(4)=ST(4)*EXPT+(YEG*SE(4)+BFR(M,30)*(SE(4)-ST(4))/DIO*NSTEP)*
1 (1.-EXPT)
      DO 200 I=1,3

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SUBROUTINE SHEAR2 (Continued)

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200 DEP(I)=ES(I)-EBAR/NSTEP-(SE(I)-ST(I)+P)/G2
DEP(4)=ES(4)-(SE(4)-ST(4))/G2
DGAMMA=SQRT(1.5*(DEP(1)**2+DEP(2)**2+DEP(3)**2)+0.75*DEP(4)
1**2)
YHL=YHL+BFR(M,31)*DGAMMA
DPLENR=((SE(1)+ST(1)-P)*DEP(1)+(SE(2)+ST(2)-P)*DEP(2)+(SE(3)+S
1T(3)-P)*DEP(3)+(SE(4)+ST(4))*DEP(4))/2./DHN*AMAX1(0.,1.-TAU)
DPLENR=ABS(DPLENR)
EP=EP+DGAMMA
PLEN=PLEN+DPLENR
C*****
C      COMPUTE PLASTIC STRAIN IN EACH ORIENTATION
C*****
STR1=ABS(SE(4))
STR2=ABS(SE(4))
STR3=0.
STR4=ABS(SE(1)-SE(2))/2.
STR5=SQRT((SE(1)-SE(3))**2+2.*SE(4)**2)/2.
STR6=SQRT((SE(2)-SE(3))**2+2.*SE(4)**2)/2.
SN=SQRT(1.5*(SE(1)**2+SE(2)**2+SE(3)**2+2.*SE(4)**2))
TEP(1)=DGAMMA/SN*STR1
TEP(2)=DGAMMA/SN*STR2
TEP(3)=DGAMMA/SN*STR3
TEP(4)=DGAMMA/SN*STR4
TEP(5)=DGAMMA/SN*STR5
TEP(6)=DGAMMA/SN*STR6
C*****
C      GROWTH PROCESS
C*****
NTOT=2*NSIZT(M)
DO 250 I=1,NTOT
250 CNA(I)=CN(I)
IF (EN .EQ. 0) GO TO 360
JN=0
DC=VMAX(M)*DIO/NSTEP
DO 350 NG=1,NANG
DGAM=0.
IF (NSIZE(M,NG) .EQ. 0. .OR. CN(JN+1) .EQ. 0 .OR. TEP(NG) .LE. 0.)
1 GO TO 345
EXPE=EXP(BFR(M,22)*TEP(NG))
NSIZEM=NSIZE(M,NG)
DO 300 I=1,NSIZEM
JN2=JN+2*(NSIZE(M,NG)+1-I)
CLA(JN2)=AMIN1(CN(JN2)*EXPE,CN(JN2)+DC)
300 DGAM=DGAM+CN(JN2-1)*3.14*BFR(M,27)*(CLA(JN2)**3-CN(JN2)**3)
IF (DGAM .LE. TEP(NG)) GO TO 345
RR=TEP(NG)/DGAM
DCR=DC*RR
EXPE=EXPE**RR
NSIZEM=NSIZE(M,NG)
DO 340 I=1,NSIZEM
JN2=JN+2*(NSIZE(M,NG)+1-I)
340 CLA(JN2)=AMIN1(CN(JN2)*EXPE,CN(JN2)+DCR)
345 TEP(NG)=AMAX1(0.,TEP(NG)-DGAM)
350 JN=JN+NSIZE(M,NG)*2
360 CONTINUE
DO 365 NG=1,NANG
365 CN(NTOT+NG)=CN(NTOT+NG)+TEP(NG)
C*****
C      NUCLEATION PROCESS
C*****
TEPM=0
DO 370 NG=1,NANG
370 TEMPM=AMAX1(TEPM,CN(NTOT+NG))
IF (TEPM .LT. BFR(M,26)) GO TO 500
JN=0
DO 450 NG=1,NANG
IF (NSIZE(M,NG) .EQ. 0) GO TO 450
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SHEAR205

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SUBROUTINE SHEAR2 (Continued)

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      IF (CN(NTOT+NG) .LT. BFR(M,26) .OR. TEP(NG) .LT. 1.E-5)      SHEAR206
1    GO TO 450                                                        SHEAR207
      DNO=TEP(NG)*BFR(M,25)*FNUC(NG)*(DPLENR/DTO*NSTEP/BFR(M,35))*2 SHEAR208
      CNR=0.                                                            SHEAR209
      NSIZE=NSIZE(M,NG)                                                SHEAR210
      DO 440 I=1,NSIZE                                                SHEAR211
      II=NSIZE(M,NG)+1-I                                              SHEAR212
      JN1=JN+2*II                                                    SHEAR213
      IF (CLA(JN1) .NE. 0.) GO TO 420                                  SHEAR214
      CLA(JN1)=BFR(M,28)*(1.-BFR(M,29)**II)/(1.-BFR(M,29)**NSIZE(M,NG)) SHEAR215
      CN(JN1)=CLA(JN1)                                                SHEAR216
420   CNL=DNO*EXP(-(CLA(JN1)+CN(JN1))/2./BFR(M,24))                  SHEAR217
      JNN=JN+2*II-1                                                  SHEAR218
      CNA(JNN)=CNL-CNR+CN(JNN)                                       SHEAR219
440   CNR=CNL                                                         SHEAR220
      EN=EN+CNL                                                       SHEAR221
450   JN=NSIZE(M,NG)*2+JN                                            SHEAR222
470   CONTINUE                                                       SHEAR223
C*****                                                             SHEAR224
C      COMPUTE TAU AND REFILL MAIN ARRAYS                            SHEAR225
C*****                                                             SHEAR226
      TAU=0.                                                           SHEAR227
      JN=0                                                            SHEAR228
      IF (EN .EQ. 0.) GO TO 500                                       SHEAR229
      DO 490 NG=1,NANG                                                SHEAR230
      TAUZ(NG)=0.                                                       SHEAR231
      IF (NSIZE(M,NG) .EQ. 0) GO TO 490                               SHEAR232
      IF (CNA(JN+1) .EQ. 0.) GO TO 490                               SHEAR233
      NSIZE=NSIZE(M,NG)                                               SHEAR234
      DO 480 I=1,NSIZE                                                SHEAR235
      JNN=JN+2*I-1                                                    SHEAR236
      CN(JNN+1)=CLA(JNN+1)                                            SHEAR237
      CN(JNN)=CNA(JNN)                                                SHEAR238
480   TAUZ(NG)=TAUZ(NG)+CNA(JNN)*CLA(JNN+1)**3                     SHEAR239
      TAU=TAU+TAUZ(NG)                                                SHEAR240
490   JN=JN+NSIZE(M,NG)*2                                           SHEAR241
      IF (TAU*VFR(M) .GE. 1.) GO TO 800                             SHEAR242
500   CONTINUE                                                       SHEAR243
      P=PE                                                             SHEAR244
      DO 550 I=1,3                                                    SHEAR245
550   ST(I)=SE(I)+P                                                  SHEAR246
      ST(4)=SE(4)                                                     SHEAR247
600   CONTINUE                                                       SHEAR248
C*****                                                             SHEAR249
C      TRANSFORMATION TO GLOBAL ORIENTATION                          SHEAR250
C*****                                                             SHEAR251
      IF (J .EQ. 17 .AND. TAU .GT. .05) PRINT 1601,ST,P            SHEAR252
1601  FORMAT(4H ST= 1P4E10.3,4H PS= E10.3)                          SHEAR253
      ST(4)=ST(4)*AMAX1(0.,(1.-(1.5*(TAUZ(1)+TAUZ(2))+3.*TAUZ(4))*VFR(M) SHEAR254
1    ))                                                                SHEAR255
      ST(1)=ST(1)*AMAX1(0.,(1.-(3.*TAUZ(1)+1.5*(TAUZ(4)+TAUZ(5))*VFR(M) SHEAR256
1    ))                                                                SHEAR257
      ST(2)=ST(2)*AMAX1(0.,(1.-(3.*TAUZ(2)+1.5*(TAUZ(4)+TAUZ(6))*VFR(M) SHEAR258
1    ))                                                                SHEAR259
      ST(3)=ST(3)*AMAX1(0.,(1.-(3.*TAUZ(3)+1.5*(TAUZ(5)+TAUZ(6))*VFR(M) SHEAR260
1    ))                                                                SHEAR261
      P=(ST(1)+ST(2)+ST(3))/3.                                         SHEAR262
      SA=(ST(1)+ST(2))/2.                                             SHEAR263
      SB=(ST(1)-ST(2))/2.*COR-ST(4)*SOR                             SHEAR264
      SXY=((ST(1)-ST(2))/2.*SOR+ST(4)*COR)*SS                       SHEAR265
      SX=(SA+SB-P)*SS                                                 SHEAR266
      SY=(SA-SB-P)*SS                                                 SHEAR267
      SZ=(ST(3)-P)*SS                                                 SHEAR268
      IF (PE .GT. 0.) P=P+PE*TAU                                       SHEAR269
      IH3=20.*TAU+2.9                                                 SHEAR270
      IF (J .EQ. 17 .AND. TAU .GT. .05) PRINT 1400,SX,SY,SZ,P,ST,EX,EY,DHSHEAR271
      IF (NCALL .GE. 3) GO TO 900                                       SHEAR272
      RETURN                                                            SHEAR273

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SUBROUTINE SHEAR2 (Concluded)

C*****	SHEAR274
C COMPLETE SEPARATION	SHEAR275
C*****	SHEAR276
800 EMU=DH/ESC(M,1)-1.	SHEAR277
PH=EMU*(ESC(M,2)+EMU*(ESC(M,3)+EMU*ESC(M,4)))	SHEAR278
PE=PH*(1.-ESC(M,9)*(DH/ESC(M,1)-1.)/2.)+DH*ESC(M,9)*EH	SHEAR279
P=AMAX1(PE,0.)	SHEAR280
SX=0.	SHEAR281
SY=0.	SHEAR282
SZ=0.	SHEAR283
SXY=0.	SHEAR284
IH3=25	SHEAR285
IF (NCALL .GE. 3) GO TO 900	SHEAR286
RETURN	SHEAR287
C * * * * *	SHEAR288
C	SHEAR289
C PRINT DAMAGE ARRAYS	SHEAR290
C	SHEAR291
C * * * * *	SHEAR292
900 IF (EN .EQ. 0.) GO TO 980	SHEAR293
IF (K .LT. KLAST) REWIND 2	SHEAR294
KLAST=K	SHEAR295
PRINT 8000,K,J,IH3,ROT,EN,TAU,EP	SHEAR296
JN=0	SHEAR297
DO 1000 NG=1,NANG	SHEAR298
TAUZ(NG)=0.	SHEAR299
NS=NSIZE(M,NG)*2	SHEAR300
IF (NS .EQ. 0 .OR. CN(JN+1) .EQ. 0.) GO TO 1000	SHEAR301
II=JN+NS-1	SHEAR302
CNA(II)=CN(II)	SHEAR303
TAUZ(NG)=CN(II)*CN(II+1)**3	SHEAR304
IF (NS .LE. 2) GO TO 975	SHEAR305
DO 970 I=3,NS,2	SHEAR306
II=NS-I+JN	SHEAR307
TAUZ(NG)=TAUZ(NG)+CN(II)*CN(II+1)**3	SHEAR308
970 CNA(II)=CN(II)+CNA(II+2)	SHEAR309
975 CONTINUE	SHEAR310
PRINT 8500,NG	SHEAR311
PRINT 9001,(CNA(JN+I),I=1,NS,2)	SHEAR312
PRINT 9002,(CN(JN+I),I=2,NS,2)	SHEAR313
WRITE (2,1902) J,K,NG	SHEAR314
WRITE (2,9001) (CN(JN+I),I=1,NS,2)	SHEAR315
WRITE (2,9002) (CN(JN+I),I=2,NS,2)	SHEAR316
1902 FORMAT(10H J = ,I10,10H K= ,I10,10H NG= ,I10)	SHEAR317
8000 FORMAT(3H K=I5,3H J=I5,5H IH3=I5,5H ROT=E10.3,4H EN=E10.3,	SHEAR318
1 5H TAU=E10.3,4H EP=E10.3)	SHEAR319
8500 FORMAT(4H NG=I5)	SHEAR320
9001 FORMAT(4H CN=10(E10.3,2X))	SHEAR321
9002 FORMAT(4H CL=10(E10.3,2X))	SHEAR322
1000 JN=JN+NS	SHEAR323
PRINT 1980,(TAUZ(I),I=1,NANG)	SHEAR324
1980 FORMAT(6H TAUZ= 9F10.6)	SHEAR325
NTOT=2*NSIZE(M)	SHEAR326
980 PRINT 9003,K,J,EP,(CN(NTOT+I),I=1,NANG)	SHEAR327
9003 FORMAT(* K=*I3,* J=*I3,* EP=* E12.4,16H TOT PL STRAIN =6F10.3)	SHEAR328
RETURN	SHEAR329
END	SHEAR330

SUBROUTINE SIGMAT

```

FUNCTION SIGMAT(LS,T)
DIMENSION PS(10),TS(10)
DATA PS/54.4E6,34.0E6,40.8E6,24.5E6,6*0./
DATA TS/0.6.E-4,8.E-4,3.2E-3,6*0./
DATA NM/4/
N=1
20 N=N+1
IF ( T .GT. TS(N) .AND. N .LT. NM) GO TO 20
SIGMAT=PS(N-1)+(PS(N)-PS(N-1))/(TS(N)-TS(N-1))*(T-TS(N-1))
RETURN
END

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```

SIGMAT 2
SIGMAT 3
SIGMAT 4
SIGMAT 5
SIGMAT 6
SIGMAT 7
SIGMAT 8
SIGMAT 9
SIGMAT10
SIGMAT11
SIGMAT12

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SUBROUTINE SSCALH

	FUNCTION SSCALH(JS)	SSCALH 2
C		SSCALH 3
C	COMPUTES RADIANT ENERGY FOR DEPOSITION IN EACH CELL AT HALFSTEP	SSCALH 4
C	PDINT AND INITIALIZES ENERGY IN NEW ZONES	SSCALH 5
C	INPUT - J(=JS), NSPEC, SDURM, TIME, DTNH, SSTOPM, DTN.	SSCALH 6
C	OUTPUT - SSCALH.	SSCALH 7
C		SSCALH 8
	INTEGER H,POROUS,PRESS,RINTER,SOLIO,SPALL	PUFCOM 2
	REAL MATL,NEM,NET,NEMH,NETH	PUFCOM 3
C	MISCELLANEOUS	PUFCOM 4
	COMMON AZERO(1),CEF,CKS,DAVG,DELTIM,OISCPT(10),OOLD,ORHO,OTMAX,	PUFCOM 5
	1 DTMIN,DTN,DTNH,DU,DX,EDLD,F,FAC,FIRST,J,JCYCS,JINIT,	PUFCOM 6
	2 JFIN,JREZON(15),JSMAX,JSTAR,JTS,LSUB(30),M,MAXPR(30),N,NCYCS,	PUFCOM 7
	3 NEDIT,NPERN,NR,NREZON,NSCRB(6),NSEPRAT,NSPALL,NTEDT,	PUFCOM 8
	4 NTEX,NTR(15),POLD,P6(20),R(30),RLAST,SLAST,SMAX,TEOIT(50),	PUFCOM 9
	5 TF,TIME,TJ,TREZON,TS,T6(20),ULAST,UOLO,UZERD,XLAST,XNOW,XOLO	PUFCOM 10
	1 ,XJDDIT(20)	PUFCOM 11
C	HALFSTEP VALUES	PUFCOM 12
	COMMOND OH,OHLAST,OUH,EH,PH,RH,RHLAST,SH,SHLAST,UH,UHLAST,XH,XHLAST	PUFCOM 13
	1 ,NEMH,NETH	PUFCOM 14
C	CONDITION INDICATORS	PUFCOM 15
	COMMOND INF,LINTER,MIRDR,NORMAL,PDROUS,PRESS,RINTER,SOLIO,SPALL	PUFCOM 16
C	CELL LAYOUT	PUFCOM 17
	COMMON DXX(30),JBNO(30),JMAT(30),NAUTO,MATL(6,2),NLAYER,NMTRLS,	PUFCOM 18
	1 THK(30)	PUFCOM 19
C		PUFCOM 20
	COMMON /RAD/ SSTOP(5),START(5),SDURM,SSTOPM,NSPEC,SSJ,JSS,IPL0T(4)	RADCOM 2
	1 ,XMAX(4),XMIN(4),YMAX(4),YMIN(4),IA(7),ITITLE(24),NARZ,TARZ	RADCOM 3
	COMMON/SS/SS(500)	SSCOM 2
C		SSCALH 12
10	SSCALH=0.	SSCALH 13
	IF (NSPEC .EQ. 0) RETURN	SSCALH 14
	IF (JS .GT. JSS) GO TO 50	SSCALH 15
	IF (SDURM .EQ. 1.) RETURN	SSCALH 16
	IF (TIME-DTNH-.5*DTN .GT. SSTOPM) RETURN	SSCALH 17
C	ENERGY ADDITION IN ACTIVE ZONES - HALF STEP	SSCALH 18
	DO 48 I=1,NSPEC	SSCALH 19
	JFINNS=JFIN*(I-1)	SSCALH 20
	IF ((TIME-.5*DTNH-START(I))*(TIME-DTNH-.5*DTN-SSTOP(I))) 46,48,48	SSCALH 21
46	SSCALH=SSCALH+SS(JFINNS+JS)*(AMIN1(SSTOP(I),TIME-.5*DTNH)-	SSCALH 22
	1 AMAX1(START(I),TIME-DTNH-.5*DTN))	SSCALH 23
48	CONTINUE	SSCALH 24
	RETURN	SSCALH 25
C	ENERGY ADDITION FOR NEW ZONES	SSCALH 26
50	JSS=JS	SSCALH 27
	DO 60 I=1,NSPEC	SSCALH 28
	JFINNS=JFIN*(I-1)	SSCALH 29
	IF (TIME-.5*DTNH .LT. START(I)) GO TO 60	SSCALH 30
	SSCALH=SSCALH+SS(JFINNS+JS)*(AMIN1(SSTOP(I),TIME-.5*DTNH)-	SSCALH 31
	1 START(I))	SSCALH 32
60	CONTINUE	SSCALH 33
75	RETURN	SSCALH 34
	END	SSCALH 35

SUBROUTINE STORR

	SUBROUTINE STORR	STORR	2
	INTEGER H,POROUS,PRESS,RINTER,SOLID,SPALL	PUFCOM	2
	REAL MATL,NEM,NET,NEMH,NETH	PUFCOM	3
C	MISCELLANEOUS	PUFCOM	4
	COMMON AZERO(1),CEF,CKS,DAVG,DELTIM,DISCPT(10),DOLD,DRHO,DTMAX,	PUFCOM	5
1	DTMIN,DTN,DTNH,DU,DX,EOLD,F,FAC,FIRST,J,JCYCS,JINIT,	PUFCOM	6
2	JFIN,JREZON(15),JSMAX,JSTAR,JTS,LSUB(30),M,MAXPR(30),N,NCYCS,	PUFCOM	7
3	NEDIT,NPERN,NR,NREZON,NSCRB(6),NSEPRAT,NSPALL,NTEDT,	PUFCOM	8
4	NTEX,NTR(15),POLD,P6(20),R(30),RLAST,SLAST,SMAX,TEDIT(50),	PUFCOM	9
5	TF,TIME,TJ,TREZON,TS,T6(20),ULAST,UOLD,UZERO,XLAST,XNOW,XOLD	PUFCOM	10
1	,XJDIT(20),MS	PUFCOM	11
C	HALFSTEP VALUES	PUFCOM	12
	COMMON DH,DHLAST,DUH,EH,PH,RH,RHLAST,SH,SHLAST,UH,UHLAST,XH,XHLAST	PUFCOM	13
1	,NEMH,NETH	PUFCOM	14
C	CONDITION INDICATORS	PUFCOM	15
	COMMON INF,LINTER,MIRROR,NORMAL,POROUS,PRESS,RINTER,SOLID,SPALL	PUFCOM	16
C	CELL LAYOUT	PUFCOM	17
	COMMON DX(30),JBND(30),JMAT(30),NAUTO,MATL(6,2),NLAYER,NMTRLS,	PUFCOM	18
1	THK(30)	PUFCOM	19
C		PUFCOM	20
C	COORDINATE ARRAYS	COORDCOM	2
	COMMON/COORD/X(200),XO(200),CHL(200),DHL(200),DPDD(200),DPDE(200),	COORDCOM	3
1	EHL(200),H(200,3),NEM(200),NET(200),PHL(200),RHL(200),SDT(200),	COORDCOM	4
2	SHL(200),T(200),U(200),YHL(200),ZHL(200)	COORDCOM	5
	COMMON/NSC/A(5000)	NSCCOM	2
	COMMON /IND/ IEOS(6),INDK(20),NALPHA,NCMP(6),NFR(6),NFOR(6),	INDCOM	2
1	NDS(6),NPR(6),NCON(6),NVAR(6)	INDCOM	3
	COMMON /JED/JEDIT(100),JNUM(100),JTYPE(100),NAME2(40),JEDSIZ,	JEDCOM	2
1	MODLUS,NERR,NJEDIT,NTAPE	JEDCOM	3
	COMMON /PES/ LVMAX,LVTOT,LVAR(200),COM(4000)	STORR	8
	DIMENSION RIMP(20),JINT(20)	STORR	9
	DIMENSION KB(300)	STORR	10
	EQUIVALENCE (A(2501),KB)	STORR	11
	IF (N.GT. 1) GO TO 100	STORR	12
C	INITIALIZATION	STORR	13
	NTAPE=3 \$ NERR=IBUF=0 \$ MODLUS=50	STORR	14
	IF (NJEDIT.GT. 45) MODLUS=25	STORR	15
	IF (NJEDIT.GT. 95) MODLUS=10	STORR	16
	IF (NJEDIT.GT. 245) MODLUS=5	STORR	17
	JEDSIZ=2500/MODLUS	STORR	18
	DO 30 I=1,10	STORR	19
30	A(2500+I)=DISCPT(I)	STORR	20
	KB(11)=MODLUS	STORR	21
	KB(12)=JEDSIZ	STORR	22
	KB(13)=JCYCS	STORR	23
	KB(14)=NJEDIT	STORR	24
	DO 40 I=1,100	STORR	25
	KB(14+I)=JTYPE(I)	STORR	26
40	KB(114+I)=JNUM(I)	STORR	27
	BUFFER OUT(NTAPE,1) (A(2501),A(2714))	STORR	28
	DO 50 I=1,20	STORR	29
	JINT(I)=JEDIT(I)	STORR	30
50	RIMP(I)=0.	STORR	31
C		STORR	32
C	BEGIN STORAGE	STORR	33
100	IF (LSUB(7).NE. 0) GO TO 600	STORR	34
	IB=JEDSIZ*IBUF	STORR	35
	A(IB+1)=N	STORR	36
	A(IB+2)=TIME*1.E6	STORR	37
	A(IB+3)=DTNH*1.E9	STORR	38
	A(IB+4)=DELTIM	STORR	39
	A(IB+5)=JTS	STORR	40
	IC=IB+5	STORR	41
	IR=0	STORR	42
	DO 500 JE=1,NJEDIT	STORR	43
	JD=JEDIT(JE)	STORR	44
	JNUMB=JNUM(JE)	STORR	45
	IF (JNUMB.GE. 4000) GOTO 200	STORR	46
C	STORAGE FOR ALL ARRAY VARIABLES	STORR	47
	A(IC+JE)=X(JNUMB+JD)	STORR	48
	GO TO 500	STORR	49
C	STORAGE FOR COM VARIABLES	STORR	50
200	IF (JNUMB.GE. 5000) GO TO 300	STORR	51
	JN=JNUMB-4000	STORR	52
	L=LVAR(JD)	STORR	53

SUBROUTINE STORR (Concluded)

	A(IC+JE)=COM(L+JN)	STORR	54
	GO TO 500	STORR	55
300	JB=JNUMB/200-24	STORR	56
	IF (JB .GT. 8) GO TO 500	STORR	57
	GO TO (310,320,330,340,350,360,370,380) JB	STORR	58
C	INTERFACE STRESS	STORR	59
310	JD=JINT(JE)	STORR	60
	A(IC+JE)=R(JD+1)	STORR	61
	GO TO 500	STORR	62
C	SECOND PRINCIPAL STRESS	STORR	63
320	IF (NALPHA .EQ. 2) GO TO 325	STORR	64
	A(IC+JE)=-0.5*SHL(JD)+1.5*PHL(JD)	STORR	65
	GO TO 500	STORR	66
325	A(IC+JE)=PHL(JD)+SDT(JD)	STORR	67
	GO TO 500	STORR	68
C	THIRD PRINCIPAL STRESS	STORR	69
330	IF (NALPHA .EQ. 2) GO TO 335	STORR	70
	A(IC+JE)=-0.5*SHL(JD)+1.5*PHL(JD)	STORR	71
	GO TO 500	STORR	72
335	A(IC+JE)=-SHL(JD)+2.*PHL(JD)-SDT(JD)	STORR	73
	GO TO 500	STORR	74
C	IMPULSE	STORR	75
340	IR=IR+1	STORR	76
	RIMP(IR)=RIMP(IR)+RHL(JD)*DTNH	STORR	77
	A(IC+JE)=RIMP(IR)	STORR	78
	GO TO 500	STORR	79
C	SPECIFIC VOLUME	STORR	80
350	IF (DHL(JD) .GT. 0.) A(IC+JE)=1./DHL(JD)	STORR	81
	GO TO 500	STORR	82
C	DEVIATOR STRESS - FIRST DIRECTION	STORR	83
360	A(IC+JE)=SHL(JD)-PHL(JD)	STORR	84
	GO TO 500	STORR	85
C	DEVIATOR STRESS - SECOND DIRECTION	STORR	86
370	IF (NALPHA .EQ. 2) GO TO 375	STORR	87
	A(IC+JE)=0.5*(PHL(JD)-SHL(JD))	STORR	88
	GO TO 500	STORR	89
375	A(IC+JE)=SDT(JD)	STORR	90
	GO TO 500	STORR	91
C	DEVIATOR STRESS - THIRD DIRECTION	STORR	92
380	IF (NALPHA .EQ. 2) GO TO 385	STORR	93
	A(IC+JE)=0.5*(PHL(JD)-SHL(JD))	STORR	94
	GO TO 500	STORR	95
385	A(IC+JE)=PHL(JD)-SHL(JD)-SDT(JD)	STORR	96
	GO TO 500	STORR	97
500	CONTINUE	STORR	98
	IBUF=IBUF+1	STORR	99
C	BUFFER OUT ARRAY ONTO NTAPE	STORR	100
	IF (IBUF .NE. MODLUS) GO TO 550	STORR	101
505	IF (UNIT(NTAPE)) 520,510,510	STORR	102
510	NERR=NERR+1	STORR	103
520	BUFFER OUT(NTAPE,1)(A(1),A(JEDSIZ*MODLUS))	STORR	104
	IF (LSUB(7) .NE. 0) GO TO 615	STORR	105
	RETURN	STORR	106
550	IF (IBUF .NE. 2*MODLUS) RETURN	STORR	107
555	IF (UNIT(NTAPE)) 570,560,560	STORR	108
560	NERR=NERR+1	STORR	109
570	BUFFER OUT(NTAPE,1)(A(JEDSIZ*MODLUS+1),A(5000))	STORR	110
	IBUF=0	STORR	111
	IF (LSUB(7) .NE. 0) GO TO 615	STORR	112
	RETURN	STORR	113
600	IF (IBUF .EQ. 0) GO TO 615	STORR	114
	IF (IBUF-MODLUS) 505,615,555	STORR	115
615	IF (UNIT(NTAPE)) 625,620,620	STORR	116
620	NERR=NERR+1	STORR	117
625	REWIND NTAPE	STORR	118
	RETURN	STORR	119
	END	STORR	120

SUBROUTINE STRES2

	SUBROUTINE STRES2(LS,IND,IH3,M,J,N,D,DOLD,RHOS,SDH,MUM,F,DTNP1,NEMSTRES2	2
1	,NET,TSR)	STRES2 3
	REAL MUM,NEM,NET	STRES2 4
	COMMON /S2/ ALF,CO,EEN,EENP1,EPN,KS,TAUEL,TAUI,TAUN,TAUO,VELS,VMU,ALCOM	2
1	ZAM,ZAMUSV,ZEP,ZEPDSV,ZEPMAXC,ZEPMAXS,ZEPSAVE,ZTAUY,ZTAUVMX	ALCOM 3
	DIMENSION TAUY(300),TAUVMX(300),EPMAXS(300),EPMAXC(300),	STRES2 6
1	EPDSV(300),EPSAVE(300),AMUSV(300),EP(300),TAU(300)	STRES2 7
	DIMENSION TSR(6,30)	STRES2 8
C		STRES2 9
C	VALUE OF IND = 0 COMPLETE CALCULATION	STRES210
C	1 COMPLETE CALC., EXCEPT FOR RESETTING ARRAYS	STRES211
C	2 ONLY RESET ARRAYS	STRES212
	IF (LS .GT. 0) GO TO 5	STRES213
	KS=0	STRES214
	ZAM= MUM	STRES215
	CO=TSR(M,15)	STRES216
	TAUO=TSR(M,16)	STRES217
	TAUI=TSR(M,17)	STRES218
	ALF=TSR(M,18)	STRES219
	DO 4 I=1,300	STRES220
	TAUY(I)=TAUVMX(I)=EPMAXS(I)=EPMAXC(I)=EPDSV(I)=EPSAVE(I)=EP(I)=	STRES221
1	TAU(I)=0.	STRES222
	AMUSV(I)=ZAM	STRES223
4	CONTINUE	STRES224
	LS=1	STRES225
5	IF (IND .EQ. 2) GO TO 100	STRES226
	ZTAUY=TAUY(J) \$ ZTAUVMX=TAUVMX(J) \$ ZEPMAXS=EPMAXS(J)	STRES227
	ZEP=EP(J) \$ ZEPMAXC=EPMAXC(J) \$ ZEPDSV=EPDSV(J)	STRES228
	ZEPSAVE=EPSAVE(J) \$ ZAM=ZAMUSV=MUM \$ TAUN=TAU(J)	STRES229
C		STRES230
C	*** TESTS FOR MATERIAL EXCEEDING MELT ENERGY ***	STRES231
C		STRES232
	IF (ZEPMAXS .LT. 0.) GO TO 90	STRES233
	IF (F.GT.0.) GO TO 10	STRES234
	ZEPMAXS=-1.	STRES235
	SDH=0.	STRES236
	GO TO 90	STRES237
C		STRES238
C	*** TEST FOR INITIALIZING SHEAR STRESS CALCULATIONS ***	STRES239
C		STRES240
10	IF (ZEPMAXS .GT. 0.) GO TO 20	STRES241
	ENU = D/RHOS	STRES242
	IF (ABS(ENU-1.) .GE. 1.E-6) GO TO 20	STRES243
	TAUEL=0.	STRES244
	GO TO 70	STRES245
C		STRES246
C	*** UPDATE STRAIN AND ELASTIC SHEAR STRESS AT TIME(N+1) ***	STRES247
C		STRES248
20	KS=0	STRES249
	VELS=-ALOG(D/DOLD)	STRES250
	EEN= ALOG(DOLD/RHOS)	STRES251
	EENP1=EEN-VELS	STRES252
	EPN=ZEP	STRES253
	ZAMUSV=AMIN1(ZAMUSV,AMAX1(MUM-ALF*ABS(EEN),1.))	STRES254
	C1=AMIN1(ZAMUSV,AMAX1(ZAM-ALF*ABS(EENP1),1.))	STRES255
	TAUEL=C1*(EENP1-1.5*EPN)	STRES256
C		STRES257
	IF (ABS(EPN) .LT. 1.E-6 .AND. ABS(TAUN) .LT. TAUO) EPN=0.	STRES258
C		STRES259
C	*** TEST 1 - TEST FOR EXCEEDING ELASTIC LIMIT AT TIME(N) ***	STRES260
C		STRES261
	IF (ABS(ZEPMAXS) .GT. 0. .OR. ABS(EPN) .GT. 0.) GO TO 30	STRES262
C		STRES263
C	*** TEST 2 - TEST FOR EXCEEDING ELASTIC LIMIT AT TIME(N+1) ***	STRES264
C		STRES265
	IF (ABS(TAUEL) .LT. TAUO) GO TO 70	STRES266
C		STRES267
C	*** INITIAL CROSSING OF ELASTIC LIMIT ***	STRES268

SUBROUTINE STRES2 (Concluded)

C	KS=1			STRES269		
	GO TO 60			STRES270		
C				STRES271		
C	*** TEST 3 - TEST FOR ELASTIC OR PLASTIC CALCULATION AT			STRES272		
C	TIME(N+1) ***			STRES273		
C				STRES274		
C				STRES275		
30	IF (ABS(ZTAUVMX).LT.ABS(TAUCL) .AND. TAUEL*ZTAUVMX.GE.0.) GO TO 40			STRES276		
C				STRES277		
C	*** TEST 4 - TEST FOR CROSSING FROM ELASTIC TO PLASTIC UNLOADING			STRES278		
C	PHASE ***			STRES279		
C				STRES280		
	IF (TAUN*TAUEL .GT. 0.) GO TO 50			STRES281		
	IF (ABS(TAUN).GT.ABS(ZTAUY) .AND. ABS(ZTAUVMX).GT.1.) GO TO 50			STRES282		
	KS=2			STRES283		
	ZTAUVMX=0.			STRES284		
	GO TO 60			STRES285		
C				STRES286		
C	*** TEST 5 - TEST FOR RELOADING OR REUNLOADING FROM AN ELASTIC			STRES287		
C	POINT AT TIME(N) ***			STRES288		
C				STRES289		
40	IF (ABS(ZTAUVMX) .GT. ABS(ZTAUY)) KS=3			STRES290		
	GO TO 60			STRES291		
C				STRES292		
C	*** TEST 6 - TEST FOR FIRST ELASTICALLY CALCULATED POINT IN			STRES293		
C	UNLOADING PHASE ***			STRES294		
C				STRES295		
50	IF (ABS(TAUN) .LE. ABS(ZTAUY)) GO TO 70			STRES296		
	KS=4			STRES297		
C				STRES298		
C	*** CALL BECOM TO CALCULATE POINT AT TIME(N+1) ON A PLASTIC			STRES299		
C	LOADING OR UNLOADING CURVE ***			STRES300		
C				STRES301		
60	CALL BECOM(D,SDH,DTNP1,J,N)			STRES302		
	GO TO 80			STRES303		
C				STRES304		
C	*** POINT AT TIME(N+1) IS ON ELASTIC CURVE ***			STRES305		
C				STRES306		
70	ZTAUY=TAUEL			STRES307		
	SDH=4.*TAUEL/3.			STRES308		
	ZEPDSV=0.			STRES309		
C				STRES310		
C	*** UPDATE TAUVMX AT TIME(N+1) ***			STRES311		
C				STRES312		
80	ZTAUVMX=AMAX1(ABS(ZTAUVMX),ABS(ZTAUY))*SIGN(1.,ZTAUY)			STRES313		
	IH3=KS			STRES314		
	SDSTORE=SDH			STRES315		
	SDH=SDH*F			STRES316		
	IF (IND .EQ. 0) GO TO 100			STRES317		
90	RETURN			STRES318		
100	TAUY(J)=ZTAUY	\$	TAUVMX(J)=ZTAUVMX	\$	EPMAXS(J)=ZEPMAXS	STRES319
	EPMAXC(J)=ZEPMAXC	\$	EPDSV(J)=ZEPDSV	\$	EPSAVE(J)=ZEPSAVE	STRES320
	AMUSV(J)=ZAMUSV	\$	EP(J)=ZEP	\$	TAU(J)=.75*SDSTORE	STRES321
	RETURN					STRES322
	END					STRES323

SUBROUTINE TSQE

```

FUNCTION TSQE(IP,PP,GRE,C,D,S,G,H,ES,R0S,EN,E,EQSTVM,EQSTAM,NCYC) TSQE 2
C TSQE 3
C** CALCULATES MU OR PTH FROM KNOWN PRESSURE AND EOS RELATION. **C TSQE 4
C IP = 0, INVERSE EOS. IP = 1, INVERSE EOS FOR PTH = ALFA*PST. C TSQE 5
C TSQE 6
NC=0 $ PO=EMUO=P11=0. $ G2=G/2 TSQE 7
ESUBC=1.0 $ ENN=0.5 TSQE 8
IF (EQSTVM .GT. 0. .AND. E .GT. ES) ESUBC=1.+ALOG(E/ES) TSQE 9
IF (EQSTVM .NE. 0.) ENN=ABS(EQSTVM) TSQE 10
ERAT=E/ES $ IF (E .GT. ES) ERAT=1.0 TSQE 11
EN2=(EN+ERAT*EQSTAM)/ESUBC $ ES2=ES*ESUBC TSQE 12
IF (NC .EQ. 0) IXX=0 TSQE 13
IF (PP .EQ. 0. .AND. E .LT. ES) GO TO 67 TSQE 14
IND = IP+1 TSQE 15
IF (PP .LE. GRE) IND = IND+2 TSQE 16
EMU1 = (PP-GRE)/C TSQE 17
NC=NC+1 $ P11=P1 TSQE 18
S4=0. TSQE 19
GO TO (10,15,20,25) IND TSQE 20
C PATH FOR COMPRESSION - SOLID PRESSURE KNOWN. ** C TSQE 21
10 WMU = 1.+EMU1 TSQE 22
PH = EMU1*(C+EMU1*(D+EMU1*S)) TSQE 23
P1 = GRE+PH*(1.-G2*EMU1/WMU) TSQE 24
EMU2 = TSQE = EMU1+(PP-P1)*(0.5/(PH*G2/WMU**2+(C+EMU1*(2.*D+EMU1*3
1. *S))*(1.-G2*EMU1/WMU))+0.5*(EMU1-EMUO)/(P1-PO)) TSQE 25
GO TO 30 TSQE 26
C PATH FOR EXPANSION - SOLID PRESSURE KNOWN. ** C TSQE 27
20 WMU=1.+EMU1 TSQE 28
S1=R0S*WMU TSQE 29
SQ=WMU**ENN TSQE 30
S2=H+(G-H)*SQ TSQE 31
IF (EN2*EMU1/WMU**2 .GT. -30.) S4=EXP(EN2*EMU1/WMU**2) TSQE 32
S3=E-ES2*(1.-S4) TSQE 33
P1=S1*S2*S3 TSQE 34
DPDMU=R0S*S2*S3+R0S*S3*ENN*(G-H)*SQ+R0S*S2*ES2*S4*EN2*(1.-EMU1)/
1 WMU**2 TSQE 35
EMU2=EMU1+(PP-P1)/DPDMU TSQE 36
EMU2=AMAX1(-1.+1.E-8*NC,AMIN1(EMU2,-1.E-8*NC)) TSQE 37
GO TO 30 TSQE 38
C PATH FOR COMPRESSION - POROUS PRESSURE KNOWN. ** C TSQE 39
15 WMU = 1.+EMU1 TSQE 40
ETA = 1.-G2*EMU1/WMU TSQE 41
PH = EMU1*(C+EMU1*(D+EMU1*S)) TSQE 42
P1 = (PH*ETA+GRE)/WMU TSQE 43
EMU2 = EMU1+(PP-P1)*(0.5/((ETA*(C+EMU1*(2.*D+EMU1*3*S))-P1-PH*G2/
1 WMU**2)/WMU)+0.5*(EMU1-EMUO)/(P1-PO)) TSQE 44
GO TO 30 TSQE 45
C PATH FOR EXPANSION - POROUS PRESSURE KNOWN. ** C TSQE 46
25 WMU = 1.+EMU1 TSQE 47
SQ=WMU**ENN TSQE 48
S2=H+(G-H)*SQ TSQE 49
IF (EN2*EMU1/WMU**2 .GT. -30.) S4=EXP(EN2*EMU1/WMU**2) TSQE 50
S3=E-ES2*(1.-S4) TSQE 51
P1=R0S*S2*S3 TSQE 52
DPDMU=R0S*S2*ES2*S4*EN2*(1.-EMU1)/WMU**3+R0S*S3*(G-H)*ENN*SQ/WMU
TSQE 53
EMU2=EMU1+(PP-P1)/DPDMU TSQE 54
EMU2=AMAX1(-1.+1.E-8*NC,AMIN1(EMU2,-1.E-8*NC)) TSQE 55
30 CONTINUE TSQE 56
IF (NC .GT. 7) PRINT 32,IP,PP,GRE,P1,EMU2,EMU1,EMUO,NC,IXX TSQE 57
32 FORMAT(* IP=*I3,* PP,GRE,P1=*1P3E10.3,* EMU2,EMU1,EMUO=*1P3E12.5,
1 * NC,IXX=*2I3) TSQE 58
IF (NC .EQ. 10) IXX=IXX+1 $ IF (IXX .GT. 10) STOP TSQE 59
IF (ABS(EMU2-EMU1) .GT. 1.E-4*AMAX1(ABS(EMU1),1.E-3)) GO TO 75 TSQE 60
TSQE=EMU2 TSQE 61
65 IF (IP .EQ. 1) TSQE=PTH=PP*(1.+EMU2) TSQE 62
67 IF (PP .EQ. 0.) TSQE=2*R0S/(1.+SQRT(1.-4./(EN+ERAT*EQSTAM)*ALOG(1.
1 -E/ES))) TSQE 63
70 RETURN TSQE 64
75 CONTINUE TSQE 65
IF (NC .EQ. 13) GO TO 65 TSQE 66
IF (ABS(PO-PP) .LT. ABS(P1-PP)) GO TO 80 TSQE 67
PO = P1 $ EMUO = EMU1 TSQE 68
TSQE 69
TSQE 70
TSQE 71
TSQE 72
TSQE 73

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SUBROUTINE TSQE (Concluded)

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80  IF (PP .GT. GRE) GO TO 90
    IF (P11 .EQ. 0. .OR. (P1-PP)*(PP-P11) .LE. 0.) GO TO 90
    EMU1=0.5*(EMU1+EMU2)
90  EMU1=EMU2
95  GO TO 8
    END

```

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TSQE      74
TSQE      75
TSQE      76
TSQE      77
TSQE      78
TSQE      79

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Appendix J

GLOSSARY

Nomenclature of Text

A_w	Atomic weight, g/mole
A_i	Coefficients of the fit between σ_a and $h\nu$
a	Coefficient of Murnaghan equation for pressure, dyn/cm^2
b	Number of cells over which a detonation front is spread, or dimensionless coefficient in Murnaghan equation for pressure
C	Bulk modulus, dyn/cm^2
C_b	$10^{-24} \text{ cm}^2/\text{barn}$, a conversion factor
C_c	$4.186 \times 10^7 \text{ erg/cal}$, a conversion factor
C_e	Effective sound speed, cm/sec
C_F	An effective coefficient of artificial viscosity
C_L	Constant in linear relation between shock velocity and particle velocity, cm/sec
C_p	Specific heat at constant pressure, $\text{dyn-cm/g/}^\circ\text{C}$
C_s	Sound speed, cm/sec
C_0	Coefficient of quadratic artificial viscosity
C_1	Coefficient of linear artificial viscosity
c	Cohesion or shear strength at zero normal stress, dyn/cm^2
D	Density, g/cm^3 ; or second coefficient in series expansion for Hugoniot pressure, dyn/cm^2
D_x	Detonation velocity, cm/sec
E	Internal energy, erg/g
E_{CJ}	Chapman-Jouguet energy, erg/g
E_e	Effective sublimation energy used in calculation of expanded states, erg/g
E_m	Melt energy, erg/g
E^P	Plastic energy, erg/g

E_{rad}	Radiant energy, erg/g
E_s	Sublimation energy, erg/g
F	Thermal reduction factor
F_{ai}, F_{bi}, F_{ci}	Coefficients in the thermal reduction series in Appendix D
F_B	Fraction of explosive detonated
F_G	Thermal softening factor applied to shear modulus
F_Y	Thermal softening factor applied to yield strength
G	Shear modulus, dyn/cm ²
H	Grüneisen ratio for expanded states
h	Planck's constant, 4.1354×10^{-18} keV-sec
I	Fluence, cal/cm ²
I_j	Cumulative impulse from the front up to the j^{th} coordinate, dyn-sec/cm ²
I_0	Incident fluence in cal/cm ²
J_1	$\sigma_1 + \sigma_2 + \sigma_3$, First invariant of the stress tensor, dyn/cm ²
J_2'	$1/2 \sigma'_{1j} \sigma'_{1j}$, Second invariant of the deviator stress tensor, dyn ² /cm ⁴
j	Coordinate or cell numbers
k	Boltzmann's constant, 8.6164×10^{-5} eV/ ⁰ K; or shear strength constant in the Coulomb model of Drucker and Prager, dyn/cm ²
M	Work-hardening modulus, dyn/cm ²
M_1	Mass of cell 1
M_{12}	Momentum between coordinates 1 and 2
N_a	6.02252×10^{23} , Avogadro's number, atom/mole
N_c	Number of cells in a zone or number of constituents in a material
N_ϕ	$\tan^2(45^\circ + \phi/2)$, a factor appearing in Coulomb strength calculations
n	Time step (cycle) number
P	Pressure, dyn/cm ²
P_{CJ}	Chapman-Jouguet pressure, dyn/cm ²
P_H	Hugoniot pressure, dyn/cm ²
Q	Artificial viscous stress, dyn/cm ²

Q_x	Energy of an explosive, erg/g
R	Total mechanical stress in direction of propagation, dyn/cm ²
R_x	Geometric ratio between successive cells
r	Radial distance in cylindrical or spherical coordinates, cm
S	Third coefficient in series expansion for Hugoniot pressure, dyn/cm ²
S_L	Coefficient in linear relation between shock velocity and particle velocity
\bar{S}	Entropy, erg/g/°C
T	Spall strength, dyn/cm ² ; or Kelvin temperature, °K; or time constant for stress relaxation, sec
T_h	Zone thickness, cm
ΔT_n	Duration of the nth source
t	Problem time, sec
t_b	Time of detonation, sec
U	Particle velocity, cm/sec
U_s	Shock velocity, cm/sec
u_{CJ}	Chapman-Jouguet particle velocity, cm/sec
V	Specific volume, cm ³ /g
V_{CJ}	Chapman-Jouguet specific volume, cm ³ /g
W	$\ln(h\nu)$, with $h\nu$ in keV
X	Coordinate location, cm
X_D	Point of initiation of a detonation, cm
\bar{X}	Midcell location, cm
ΔX	Cell size in direction of propagation, cm
ΔX_f	Last cell in a zone, cm
ΔX_1	First cell in a zone, cm
Y	Yield strength, dyn/cm ²
Y_D	Work-hardening coefficient, dyn/cm ² /(g/cm ³)
Y_τ	Yield stress in shear, dyn/cm ²
Z	Cell mass (g/cm ² , g/cm, or g for planar, cylindrical, or spherical flow)
α	Volumetric thermal expansion coefficient, 1/°C or coefficient in the Coulomb model of Drucker and Prager

β	Coulomb coefficient for the effect of pressure on yield strength
Γ	Grüneisen's ratio
Γ_e	Effective Grüneisen ratio used in calculation of expanded states
γ	Shear strain, or polytropic gas constant
δ	Added change in thickness between successive cells in an arithmetic layout
δ_{ij}	Kronecker delta: zero for $i \neq j$; one for $i = j$
ϵ	$1 - \rho_0/\rho$, Lagrangian strain
ϵ_{ij}	Strain tensor
ϵ_{ij}^E	Component of the elastic strain tensor
ϵ_{ij}^P	Component of the plastic strain tensor
ϵ_{EL}	$Y(2G)$, strain to the Hugoniot elastic limit
ϵ_{-P}	Equivalent plastic strain, defined in Eq. (4.33)
θ	Temperature, $^{\circ}\text{C}$; or angle between the radiation direction and normal incidence on the layer
$d\theta$	Small angle containing the typical cell in cylindrical or spherical geometry
λ	Proportionality factor used in plasticity calculations, cm^2/dyn
μ	$\rho/\rho_0 - 1$, a strain
μ_a	Linear absorption coefficient, $1/\text{cm}$
ν	Vibration frequency, Hz
ξ_i	Dimensionless parabolic interpolation factors
ρ	Density, g/cm^3
ρ_0	Initial density
σ_{ij}	Thermodynamic stress in i direction on j plane, dyn/cm^2
σ'_{ij}	Deviator stress in i direction on j plane, dyn/cm^2
σ'_{ij}^N	Deviator stress computed on an elastic basis, dyn/cm^2
$\bar{\sigma}$	Effective stress $\sqrt{\frac{3}{2} \sigma'_{ij} \sigma'_{ij}}$, dyn/cm^2
$\bar{\sigma}^N$	Effective stress based on elastically computed stresses, $\sqrt{\frac{3}{2} \sigma'^N_{ij} \sigma'^N_{ij}}$, dyn/cm^2

σ_a	Mass absorption coefficient, barns/atom
σ_N	Normal stress, dyn/cm ²
σ_r	Radial stress, dyn/cm ²
σ_θ	Circumferential stress, dyn/cm ²
τ	Shear stress, dyn/cm ²
τ_c	Shear yield stress, dyn/cm ²
ϕ	Angle of internal friction, or yield function. Yield occurs for $\phi = 0$. For negative values of ϕ , behavior is elastic; positive values are not permitted.
ω	$h\nu/KT$, a nondimensional quantity proportional to photon energy

Nomenclature of the PUFF code

AK(M)	Initial bulk modulus of a porous material, dyn/cm^2 (input)
ANGLE	Angle between the direction of radiation and the normal to the layers, degrees (input)
BURN(M)	Point of initiation of detonation, cm (input)
CFP	Abbreviated symbol for the indicators NCMP(M), NFR(M), and NPOR(M)
CHL(J)	Sound speed, cm/sec
CKS	Maximum distance of wave front. Computation stops if wave reaches CKS (input), cm
COM	Array containing additional variables for special material models; see Appendix C
COSQ	Indicator used with NYAM (see NYAM)
COSQ(M)	Coefficient of quadratic artificial viscosity (input)
C1(M)	Coefficient of linear artificial viscosity in compression (input)
C2(M)	Coefficient of linear artificial viscosity in tension (input)
DELFIN	Size of the last cell in a zone, cm. Used for arithmetic cell layout (input)
DELTIM	Calculational time for a cycle, sec
DELX	Size of the first cell in a zone, cm. Used for arithmetic and geometric cell layout (input)
DET(M)	Detonation velocity of an explosive, cm/sec
DHL(J)	Cell density, g/cm^3
DIST(M)	Number of cells over which a detonation front is spread, cm (input)
DPY	Abbreviated symbol for the indicators NDS(M), NPR(M), and NYAM
DTN	Previous time increment in the calculation, sec
DTNH	Current time increment in the calculation, sec
DTMAX	Time step desired after automatic rezoning, sec. If negative, |DTMAX| is the number of cells desired in the layer numbered |NREZON| (input)
ECAL	Fluence, cal/cm^2 (input)
ECJ(M)	Chapman-jouguet energy, erg/g
EHL(J)	Internal energy, erg/g
EI	Energy at a specific photon energy in an arbitrary spectrum, cal/cm^2 (input)

EMELT	Indicator used with NYAM (see NYAM)
EMELT(M)	Internal energy at melting, erg/g (input)
EQSTC(M)	Bulk modulus, dyn/cm^2 . Read in as C for C,D,S Hugoniot pressure form, C_L for the linear $U_s - U$ form, or a/b for the Murnaghan form (input)
EQSTD(M)	Second coefficient in the expansion for Hugoniot pressure, dyn/cm^2 . Read in as D for C,D,S form, S_L for the linear $U_s - U$ form, or b for the Murnaghan form (input)
EQSTE(M)	Sublimation energy, erg/g (input)
EQSTG(M)	Grüneisen ratio (input)
EQSTH(M)	Grüneisen ratio for expanded states (input)
EQSTS(M)	Third coefficient in the expansion for Hugoniot pressure, dyn/cm^2 . Read in as S for C,D,S form, 1.0 for Murnaghan or 2.0 for linear $U_s - U$ form (input)
EXMAT(M,I)	Array containing additional property data I = 1 contains Coulomb coefficient (input) I = 3 contains initial sound speed of porous material or explosive
FBURN	Fraction of explosive detonated
GMELT	Indicator used with NYAM (see NYAM)
H(J,I)	Indicator arrays. H(J,1) indicates solid or porous state; H(J,2) shows coordinate type and path to be followed in HYDRO; H(J,3) indicates the material state in the cell
J	Coordinate or cell number
JBND(L)	Final J value of the Lth layer
JCYCS	Number of calculational cycles at which computation will terminate (input). If JCYCS is set to zero, only a layout is performed
JFIN	Last coordinate value, equals last cell number + 2
JMAT(L)	Material number in layer L. JMAT(L) = 0 if the Lth layer is a gap (input)
JREZON	Rightmost coordinate of a nonautomatic rezone (input)
JSTAR	The J value of the right-most active cell
JTS	J value of cell governing time step. In SCRIBE histories, JTS is listed as JTS plus 1000 times the number of spalled interfaces
LSUB()	Indicator array, mainly used for initializing special material model subroutines. LSUB(7) is set to 1 at several places in the program to halt calculations because of an error

LVAR(J)	Array containing starting location of additional variables for cell J in the COM array; see Appendix C
M	Material number
MATFL	Indicator for problem type (input). MATFL > 0 means impact or explosion and MATFL is the last layer in the flyer plate MATFL = 0. Radiation deposition MATFL = -1 Mirror or symmetric impact MATFL = -2 Pressure boundary at J = 1 MATFL = -3 Pressure boundary at J = JFIN
MATL	Array containing the material name (input)
MELT	Indicator used with NYAM (see NYAM)
MU(M)	Shear modulus, dyn/cm ² (input)
MUP(M)	Initial shear modulus in porous material, dyn/cm ² (input)
N	Current calculation cycle
NALPHA	Geometry indicator: 0 or 1 for planar, 2 for cylindrical, and 3 for spherical (input)
NARB	Indicator for an arbitrary deposition (depth-dose profile), (input) 0 Normal operation 1 Normalize energy to the ECAL designated -I Modify X-scale to fit the present density (I is arbitrary) -1 Modify X-scale to fit the present density and normalize to the ECAL designated
NARZ	Maximum number of automatic rezones (input)
NBB	Number of black bodies in a spectrum (input)
NCELLS	Number of cells in a zone (input)
NCMP(M)	Indicator for a model for a composite material: zero for no model, 1 for REBAR (input)
NCON(M)	Indicator for number of constituents in a mixture or compound. Used for radiation absorption calculations only (input)
NDS(M)	Indicator for a deviator stress model: zero for standard model (Section 4), 1 for one-parameter stress relaxation model, 2 for Band dislocation model, 3 for Gilman dislocation model, 4 for two-parameter stress relaxation model, 5 for Bauschinger model, 6 for Read relaxation model for beryllium (input)
NEDIT	Number of cycles between calls to EDIT. EDIT calls may be controlled by either TEDITs or NEDIT, or by both
NEM(J)	Number of mobile dislocations or relative void volume
NET(J)	Total number of dislocations or number of voids/cm ³
NFR(M)	Indicator for a fracture model: zero for no model, 1 for DFRAC, 2 for BFRAC, 3 for SHEAR2, and 4 for both BFRAC and SHEAR2 (input)

NJEDIT	Number of lines of data in the request for historical listings (input)
NHNU	Number of energy values in an arbitrary spectrum (input)
NLAYER	Number of layers, counting blank layers or gaps. A hollow cylinder or sphere is represented with a gap as the first layer (input)
NMTRLS	Number of materials for which data are supplied in the problem input (input)
NPOINT	Number of points in a depth-dose profile (input)
NPOR(M)	Indicator for a porous material: zero for no model, 1 for POREQST, 2 for PORHOLT, 3 for PEST, and 4 for CAP (input)
NPR(M)	Indicator for pressure model: zero for EQST, 1 for explosive, 2 for ESA, 3 for Philco-Ford equation of state, 4 for variable modulus model (HYPO), 5 for GRAY equation of state, 6 for tabular equation of state, and 7 for a linear equation of state provided in HAFSTEP (input)
NREZON	Rezone control parameter. For positive values, NREZON means the number of rezones requested. A negative NREZON indicates automatic rezoning. See Section 5.2 for further information on rezone controls (input)
NSCRB	An array of indicators for controlling radiation deposition plots from DEPOS (input)
NSPEC	Number of spectra (input)
NTEDT	Number of time edits requested at specified times (input)
NTR	Number of the TEDIT for which a rezone is requested (input)
NVAR(M)	Number of extra variables required for each cell for the material model being used. Current models and extra variables required are: BFRACT2 (11), BFRACT3 (20), HYPO (3), PEST (5), REBAR (7), and SHEAR2 (variable) (input)
NYAM	Indicator for the number of lines containing spall strength, viscosity, thermal strength reduction, and yield data. The first word on each of these lines contain letters showing the data type (input) C (COSQ) or V (VISC): artificial viscosity E (EMELT) or M (MELT): thermal strength reduction factor GM (GMELT): thermal reduction for shear modulus T (TENS): spall strength Y (YIELD): yield strength, shear modulus, work-hardening modulus
NZONES	Number of zones in a layer (input)
PCJ(M)	Chapman-Jouguet pressure dyn/cm^2
PHL(J)	Pressure, dyn/cm^2 (positive in compression)

U(J)	Particle velocity, cm/sec
UZERO	Flyer velocity, cm/sec (input)
VCJ(M)	Chapman-Jouguet specific volume, cm^3/g
VISC	Indicator used with NYAM (see NYAM)
X(J)	Eulerian location of coordinate J, cm
YADD(M)	Work-hardening coefficient, dyn/cm^2 during input and $\text{dyn}/\text{cm}^2/(\text{g}/\text{cm}^3)$ after resetting in GENRAT (input)
YHL(J)	Yield strength
YIELD	Indicator used with NYAM (see NYAM)
YOS	Initial yield strength, dyn/cm^2 (input)
ZHL(J)	Cell mass; g/cm^2 , g/cm , or g for planar, cylindrical, or spherical geometry

P6	Pressure coefficient in prescribed exponential pressure boundary. P6(1) is for left boundary, P6(2) for right (input), dyn/cm ²
QEXPL(M)	Energy of an explosive, erg/g (input)
RATIO	Geometric ratio used for geometric cell layout (input)
RHL(J)	Mechanical stress in the direction of propagation, dyn/cm ² (positive in compression)
RHO(M)	Initial cell density, g/cm ³ (input)
RHOS(M)	Initial solid density, g/cm ³ (input)
SDH	Deviator stress in the direction of propagation, dyn/cm ² (positive in compression)
SDT(J)	Deviator stress in the transverse (circumferential) direction in cylindrical geometry, dyn/cm ²
SDURM	An indicator for radiation calculations. Set to the longest duration of an active radiation source during radiation; reset to 1.0 after radiation is complete, sec
SHL(J)	Stress in direction of propagation, dyn/cm ² (positive in compression)
SS	Spectral energy that is gradually deposited into the cells during radiation
SSTOPM	Maximum stop time for radiation deposition, sec
SSTOP(N)	Stop time of Nth radiation source, sec (input)
START(N)	Start time of Nth radiation source, sec (input)
T(J)	Spall strength, dyn/cm ² (negative)
TARZ	Problem time when automatic rezoning is terminated, sec (input)
TBL	hν, photon energy, keV (input)
TEDIT	Specified time at which an edit is requested (input), sec
TEMP	Black body temperature, keV (input)
TENS	Indicator used with NYAM (see NYAM)
TENS(M,I)	Spall strength, dyn/cm ² (input), I = 1 for solid I = 2 for porous I = 3 for interface with following material
TH	Zone thickness, cm (input)
TIME	Current time in the problem, sec
TREZON	Time interval between automatic rezones, sec (input)
TS	Stop time for the problem, sec (input)
TSR	Array used for deviator stress and fracture properties (input)
T6	Time factor in prescribed exponential pressure boundary. T6(1) is for left boundary, T6(2) for right (input), sec

REFERENCES

1. J. von Neumann and R. D. Richtmyer, "A Method for the Numerical Calculation of Hydrodynamic Shocks," J. Appl. Phys., 21, p. 232 (1950).
2. R. D. Richtmyer and K. W. Morton, Difference methods for Initial-Value Problems, 2d ed. (Interscience Publishers, New York, 1967).
3. J. K. Crosby and S. P. Gill, "Feasibility Study of an Explosive Gun," Final Report No. 2, Stanford Research Institute, Contract NAS2-1361, for NASA-Ames Research Center (May 1966).
4. O. Nance and H. A. Smith, "An X-Ray Effects Code (U)," UCRL-5616-T, University of California, Lawrence Radiation Laboratory, Livermore, California (July 1959) (Secret).
5. O. Nance, M. Wilkins, I. Blandford, and H. Smith, "SHARP--A One-Dimensional Hydrodynamics Code for the IBM 704," UCRL-5206-T, University of California, Lawrence Radiation Laboratory, Livermore, California (April 1958).
6. L. E. Bothell et al., "Equation of State for the PUFF Code (U)," AFSWC-TDR-62-147, Research Directorate, Air Force Special Weapons Center, Kirtland Air Force Base, New Mexico (1963) (Confidential).
7. L. E. Bothell et al., "Predictions of the Response of Materials to X-Rays (U)," AFSWC-TDR-62-152, Research Directorate, Air Force Special Weapons Center, Kirtland Air Force Base, New Mexico (1963) (Secret-RD).
8. L. E. Bothell, "Theoretical Calculations of Shock Propagation in Ablative Materials (U)," AFSWC-TDR-61-63, Research Directorate Air Force Special Weapons Center, Kirtland Air Force Base, New Mexico (March 1962) (Secret-RD).
9. L. E. Bothell, C. E. Archuleta, and R. E. Franke, "PUFF III, Variable Time Step, and Mass Absorption Coefficient Codes (U)," AFSWC-TDR-62-151, Research Directorate, Air Force Special Weapons Center, Kirtland Air Force Base, New Mexico (1963) (Secret-RD).
10. L. E. Bothell, C. E. Archuleta, and R. E. Franke, "PUFF IV Hydrocode, Part I (U)," Kaman Nuclear Report KN-664-65-1, Contract DA-01-021-AMC-90023(Y) (November 1965) (Secret-RD).
11. L. E. Bothell and C. E. Archuleta, "PUFF IV-EP Hydrocode, Part I (U)," Kaman Nuclear Final Report KN-664-67-1, Contract DA-01-021-AMC-90023(Y) (January 1967) (Secret-RD).

12. L. E. Bothell and C. E. Archuleta, "PUFF V-EP CODE (U)," Kaman Nuclear Final Report, KN-703-67-101(R), Contract DA-01-021-AMC-90029(Y), for Sentinel Systems Command, SENSC-DRS, Redstone Arsenal, Alabama (December 15, 1967) (Secret-RD).
13. R. A. Grandey, "PUFF V-TS Computer Program (U)," AFSWC-TDR-62-76, Research Directorate, Air Force Special Weapons Center, Kirtland Air Force Base, New Mexico (1963) (Confidential).
14. R. G. Allen, L. K. Goodwin, et al., "A Study of X-Ray Counter-measure Methods (U)," Technical Report No. AFWL-TDR-64-42, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico (June 1964) (Secret-RD).
15. R. N. Brodie and J. E. Hormuth, "The PUFF 66 and P PUFF 66 Computer Programs," Research and Technology Division, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico (May 1966).
16. W. Herrmann, P. Holzhauser, and R. J. Thompson, "WONDY, A Computer Program for Calculating Problems of Motion in One Dimension," SC-RR-66-601, Sandia Corporation, Albuquerque, New Mexico (February 1967).
17. Lynn Seaman, "SRI PUFF 3 Computer Code for Stress Wave Propagation," Technical Report No. AFWL-TR-70-51, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico (September 1970).
18. R. H. Fisher, G. A. Lane, and R. A. Cecil, "RIP, A One-Dimensional Material Response Code," Report No. 3SR-751-I, by Systems, Science and Software for Defense Nuclear Agency, Washington, D.C. (September 1972).
19. L. Seaman, R. F. Williams, J. T. Rosenberg, D. C. Erlich, and R. K. Linde, "Classification of Materials by Shock Properties," Final Report No. AFWL-TR-69-96 by SRI for Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico (November 1969).
20. L. Seaman and J. T. Rosenberg, "Characterization of Homogeneous Materials in Compression and Tension," Final Report No. AFWL-TR-73-15 by SRI for Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico (January 1973).
21. D. A. Shockey, L. Seaman, and D. R. Curran, "Dynamic Fracture of Beryllium under Plate Impact and Correlation with Electron Beam and Underground Test Results," Final Report No. AFWL-TR-73-12 by SRI for Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico (January 1973).
22. L. Seaman, T. W. Barbee, Jr., and D. R. Curran, "Dynamic Fracture Criteria of Homogeneous Materials," Final Report No. AFWL-TR-71-156 by SRI for Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico (December 1971).
23. L. Seaman and D. A. Shockey, "Models for Ductile and Brittle Fracture for Two-Dimensional Wave Propagation Calculations," Final Report AMMRC-CTR-75-2 by SRI for Army Materials and Mechanics Research Center, Watertown, Massachusetts (February 1975).

24. D. A. Shockey, L. Seaman, D. R. Curran, P. S. De Carli, M. Austin, and J. P. Wilhelm, "A Computational Model for Fragmentation of Armor Under Ballistic Impact," Final Report by SRI for U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland (December 1973).
25. L. Seaman, D. R. Curran, and D. A. Shockey, "Computational Models for Ductile and Brittle Fracture," J. Appl. Phys., Vol. 47, No. 11, pp. 4814-4826 (November 1976).
26. T. Barbee, L. Seaman, and R. C. Crewdson, "Dynamic Fracture Criteria of Homogeneous Materials," Technical Report No. AFWL-TR-70-99 by SRI for Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico (November 1970).
27. L. K. Goodwin, L. A. Johnson, and R. S. Wright, "An Equation of State of Metals," DASA-2286, Aeronutronic Division of Philco-Ford Corporation, Newport Beach, California (April 1969).
28. L. Seaman, R. E. Tokheim, and D. R. Curran, "Computational Representation of Constitutive Relations for Porous Materials," Final Report No. DNA 3412F by SRI for Defense Nuclear Agency, Washington, D.C. (May 1974).
29. E. B. Royce, "GRAY, a Three-Phase Equation of State for Metals," UCRL-51121, Lawrence Livermore Laboratory, Livermore, California (September 3, 1971).
30. D. E. Grady, C. W. Smith, G. M. Muller, K. D. Mahrer, and C. F. Petersen, "In Situ Constitutive Relations of Soils and Rocks," Final Report DNA-3671Z by SRI for Defense Nuclear Agency, Washington, D.C. (March 1974).
31. L. Seaman and R. K. Linde, "Distended Material Model Development, Vol. 1: Experiments and Theory for the Model," AFWL-TR-68-143, Stanford Research Institute, Menlo Park, California (May 1969).
32. A. Holt, A. Kusubov, M. Carroll, and B. Hord, "Stress-Wave Propagation in Distended Asbestos Phenolic," UCRL-51120, Lawrence Livermore Laboratory, Livermore, California (September 3, 1971).
33. Y. M. Gupta and L. Seaman, "Local Response of Reinforced Concrete to Missile Impacts," Final Report by SRI for Electric Power Research Institute, Palo Alto, California (October 1977).
34. L. Seaman, D. A. Shockey, D. R. Curran, and R. E. Tokheim, "Development of a Shear Band Model for Fragmentation in Exploding Cylinders," Final Report by SRI for Naval Surface Weapons Laboratory, Dahlgren, Virginia (August 1975).
35. D. C. Erlich, L. Seaman, D. A. Shockey, and D. R. Curran, "Development and Application of a Computational Shear Band Model," Final Report by SRI for U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland (June 1977).
36. H. E. Read and R. A. Cecil, "A Rate-Dependent Constitutive Model for Shock-Loaded S-200 Beryllium," DNA-2845F, Systems, Science and Software, La Jolla, California (February 1972).

37. M. H. Rice, R. G. McQueen, and J. M. Walsh, "Compression of Solids by Strong Shock Waves," Solid State Physics, Vol. 6, F. Seitz and D. Turnbull, Eds. (Academic Press, New York, 1958).
38. D. R. Stull et al., JANAF Thermochemical Tables, Dow Chemical Company, Contract No. AF 04(611)-7554, sponsored by Project Principia of the Advanced Research Projects Agency (August 1965), with Addenda published in August 1966 and August 1967.
39. K. Terzaghi, Theoretical Soil Mechanics (John Wiley and Sons, Inc., New York, 1943).
40. D. C. Drucker and W. Prager, Soil Mechanics and Plastic Analysis or Limit Design," Quarterly of Applied Mathematics, Vol. 10, p. 157 (1952).
41. W. H. McMasters et al., "Compilation of X-ray Cross Sections," University of California, Livermore, Report No. UCRL-50174, Section II Revision 1 (May 1969).
42. R. H. Fisher and J. W. Wiehe, "A User's Guide to the FSCATT Code," Final Report No. DASA 2618 by Systems, Science and Software for Defense Atomic Support Agency, Washington, D.C. (November 1970).
43. F. W. Sears, Optics (Addison-Wesley Press, Inc., Cambridge, Massachusetts, 1949).
44. J. Taylor, Detonation in Condensed Explosives (Clarendon Press, Oxford, 1952).
45. R. Hill, The Mathematical Theory of Plasticity (Clarendon Press, Oxford, 1950).
46. M. L. Wilkins, "Calculation of Elastic-Plastic Flow," University of California, Lawrence Radiation Laboratory, Livermore, California, in Fundamental Methods in Hydrodynamics, Vol. 3 (Academic Press, New York and London, 1964).

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